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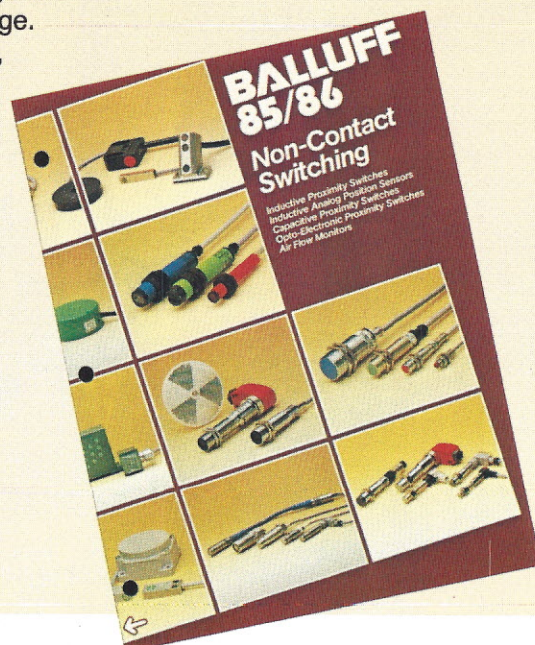
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About the cover: This month's cover photo, provided by Eaton-Kenway, depicts the Kenway Unit Load®, a storage and retrieval robot. The device can travel through narrow aisles, picking up a 16,000 lb. payload and automatically storing it at heights of 90 ft. or more. The system computer remembers load locations and also maintains accurate inventory records.

Automatic Or Autonomous?

BY CARL HELMERS

Automatic guided vehicles and autonomously guided vehicles are two ends of the vehicle guidance concept spectrum. The idea of vehicle systems unifies the two. As we go from "automatic" toward "autonomous," the intelligence of the systems using the vehicles increases dramatically. The concept of guidance goes from literal concrete and steel to the much more abstract idea of moving from place to place according to some plan or algorithm.

At one end of the spectrum we have the commercially proven class of automatic guided vehicles (AGVs) that follow physically mapped tracks. Historically, the railroad can be considered the first automatic guided vehicle, with a close cousin in the tracked conveyor systems of factories. Although the velocity of trains is usually controlled by human operators, the guideway of steel rails is responsible for directional control. As rigid infrastructures, the early automatic guided vehicle concepts were just as inflexible as steel rails, with a similarly high cost of modification and change.

As designs evolved, the track concept remained but its implementation cost came down. Early approaches to the conventional factory floor AGV involved replacing the physical track of the railroad with guide slots in the floor. Closely related to this, the concealed signal wire/wire follower technique was still inflexible but did away with the problem of human-generated trash clogging the slots. While the physical slot follower and the railroad or conveyor method could be controlled with electromechanical logic, the newer concepts introduced the virtual requirement that electronics be on board the vehicle.

As guidance electronics advanced, we saw the introduction of concepts such as infrared beacons, ultrasonic ranging systems, and paint stripes as guidance methods. These technologies opened up new possibilities for automatic commercial office delivery vehicles and flexible AGVs for industrial applications. With recent developments in LSI digital computers, the intelligence mounted on board such transport subsystems has increased—but primarily for purposes of integrating these devices into larger systems. With the era of on-board computers, the automatic has been gradually transformed into a version of "autonomous" while the "guided" has been generalized into a very loosely coupled interaction with an environment that contains navigation guideposts and benchmarks.

No vehicle system has a completely solitary existence. However autonomously it may operate, a vehicle is a physical conveyance transporting itself and/or its contents from physical place to physical place. It has a purpose and a function within a more global system or set of human purposes and functions.

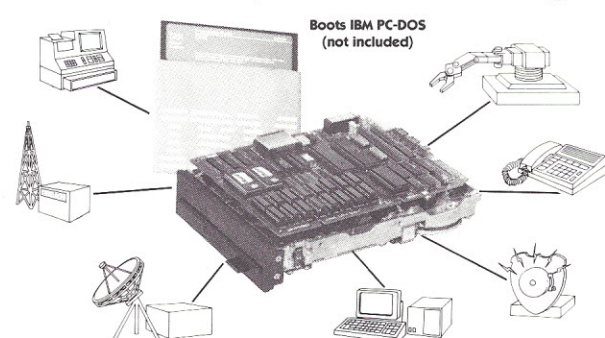
The automatic guided vehicle—as well as the newer concepts of the autonomous vehicle—fits into the larger context of human beings' needs and engineers' answers to those needs. The AGV as a batching platform for movement of materials and material pallets in a manufacturing plant is one variation. The AGV as a navigating trackless material/manipulator mover in a clean room environment is a variation just now coming to fruition. The AGV as a freely navigating sentry is being explored by industry as well as by the military. The AGV as a weapon has been with us since the first pilotless "guided missiles" at the end of the first half of this century. The AGV as a mostly autonomous communicating space probe is a triumph of engineering that was only a dream when many of us were children. While the automatically driven automobile is a dream now, combinations of sensors and semiconductor intelligence will ultimately bring it about. Its usefulness is too obvious not to find a market.

For More Information About Autonomous Vehicles

Today's practical autonomous vehicles are only a beginning. More concepts and implementations within engineering systems will be developed as this line of the robotics engineering arts develops. The field has even matured sufficiently to have given birth to a trade organization. Readers interested in further information should contact the Association for Unmanned Vehicle Systems, 1133 Fifteenth Street NW, Washington, DC 20005, and ask for the recently published brochure, "Unmanned Vehicles: Mind in Machine."

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Calendar

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2-3. **Artificial Intelligence—Technology & Applications.** Meridian Hotel, Boston, MA. Contact: EFDPA Conferences, Technology Training Corporation, Dept. AI, PO Box 3608, 3420 Kashiwa St., Torrance, CA 90510-3608, telephone (213) 534-3922.

3-5. **Robots in Spray Finishing.** GMI Engineering & Management Institute, Flint, MI. Contact: Society of Manufacturing Engineers, Special Programs Department, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-0039.

4. **Expert Systems and Prolog Videoconference.** Available to universities, companies, and Institute of Electrical and Electronics Engineers entity-sponsored locations. Contact: IEEE Continuing Education Department, IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854-4150, telephone (201) 981-0060, ext. 329.

4-6. **SNA Concepts, Design and Implementation.** Hilton Inn Columbia, Columbia, MD. Contact: Center for Advanced Professional Education, 1820 E. Garry St., Suite 110, Santa Ana, CA 92705, telephone (714) 261-0240. (To be repeated 18-20 December at Emerald of Anaheim, Anaheim, CA.)

8-11. **Chicago '85: Integrating People and Technology.** (Preconference seminars 5-8.) Chicago, IL. Contact: Institute of Industrial Engineers, 25 Technology Park/Atlanta, Norcross, GA 30092, telephone (404) 449-0460.

11-13. **Second International Conference on Artificial Intelligence Applications.** Fontainebleau Hilton, Miami Beach, FL. Contact: Artificial Intelligence Applications, PO Box 639, Silver Spring, MD 20901.

11-13. **Winter National Design Engineering Show and Conference.** Convention Center, Anaheim, CA. Contact: Show Manager, Winter National Design Engineering Show, 999 Summer St., Stamford, CT 06905, telephone (203) 984-8287.

JANUARY

21-23. **Artificial Intelligence: Current Applications, Trends, and Future Opportunities.** Massachusetts Institute of Technology, Cambridge, MA. Contact: M.I.T. Seminar Office, Center for Advanced Engineering Study, Room 9-335, 105 Massachusetts Ave., Cambridge, MA 02139, telephone (617) 253-7406.

28-30. **Charlotte Tool & Manufacturing Engineering Conference**

& Exposition. Charlotte Convention Center, Charlotte, NC. Contact: SME Technical Activities Dept., Society of Manufacturing Engineers, One SME Dr., Dearborn, MI 48121, telephone (313) 271-1500.

FEBRUARY

4-6. **7th International Conference on Assembly Automation.** Zurich, Switzerland. Contact: Conference Manager (ICAA-7), IFS (Conferences) Ltd, 35-39 High St., Kempston, Bedford MK42 7BT, England, telephone (0234) 853605.

11-13. **Orlando Manufacturing Productivity Conference and Exposition.** Orlando Expo Centre, Orlando, FL. Contact: Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121.

MARCH

3-6. **Flexible Manufacturing Systems.** Hyatt Regency O'Hare, Rosemont, IL. Contact: John McEachran, Special Programs Division, Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500.

3-6. **Agri-Mation 2 Conference and Exposition.** Chicago Hilton Hotel and Towers, Chicago, IL. Contact: Public Relations Depart-

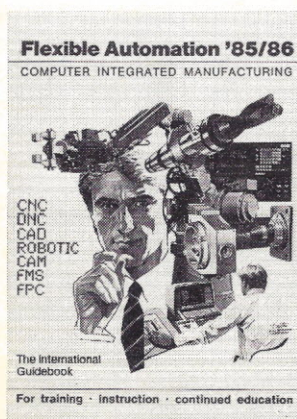
ment, Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-0777.

12-14. **Artificial Intelligence for the Automotive Industry—The Demystification.** Westin Hotel, Detroit, MI. Contact: Dale Mason, SME Technical Activities Dept., Computer and Automated Systems Association of SME, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500, ext. 375.

17-20. **WESTEC '86.** Los Angeles Convention Center, Los Angeles, CA. Contact: Society of Manufacturing Engineers, One SME Drive, PO Box 930, Dearborn, MI 48121, (313) 271-0023, ext. 328.

18-21. **International Handling & Storage Exhibition—IHSE '86.** National Exhibition Centre, Birmingham, England. Contact: Keith Harris, Trinity Publishing Ltd., Station Approach, Long Lane, Hillingdon, Middlesex UB10 9NR, England.

19-21. **3rd International Conference on Automated Materials Handling.** Metropole Hotel, National Exhibition Centre, Birmingham, England. Contact: IFS (Conferences) Ltd., 35-39 High St., Kempston, Bedford MK42 7BT, England, telephone (0234) 853605.



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AGILE AUTONOMOUS VEHICLES IN THE JUST IN TIME ENVIRONMENT

John M. Holland
Cybermation Inc.
5457 JAE Valley Road
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Great changes are coming to the factory floor. Manufacturing plants, once bastions of conservatism, are now the scene of a technological revolution. Among the new technologies are CAD (Computer Aided Design), CAM (Computer Aided Manufacturing), CIM (Computer Integrated Manufacturing), and JIT (Just In Time) manufacturing.

To be added to these is AAV, the Agile Autonomous Vehicle, and whether or not the acronym endures, there is very little doubt that the class of machine it describes will be widely used in the near future. An AAV may be thought of as a subspecies of the genus AGV (Automatic Guided Vehicle). The term AGV usually brings to mind big lumbering flatcar-like vehicles (called unit load vehicles) slowly following buried wires or other physical paths around the floor of a factory or warehouse. In fact, AGVs come in a wide variety of forms including small forklift vehicles (pallet trucks), trains pulled by driverless tractors, and giant crane-like machines.

Despite their variety, AGVs do share some characteristics: they tend to be designed for relatively heavy loads (1000 lbs and up), and they tend to use physical path-following for navigation. This path may consist of a buried wire, a row of magnets, a painted stripe, an invisible fluorescent line, or any of a number of other techniques. Although some AGVs can communicate with a host computer, control is generally relatively loose. Except for the forklifts, most AGVs are not self-loading, and those that are often require

an operator during that phase of operation. All of these types of AGVs will continue to find application on the factory and warehouse floors, but to understand the need for still another type of AGV, one must understand the concept of JIT manufacturing.

THE JIT ENVIRONMENT

In the past, most manufacturing operations kept ample stocks of raw material inventory on hand at all times. Fear that the factory could be brought to a halt for want of a few screws or other components drove managers to order far ahead of predicted needs. Indeed, one of the problems was the difficulty of predicting needs. The number of parts that would be rejected along the way was seldom known. Furthermore, if the factory offered products with a variety of options, correlating between incoming orders, materials on hand, work in process, and the parts required to complete the orders was an extremely difficult task.

All the information required to do this correlation was available in the plant—it just couldn't be put together in time to be useful. It couldn't, that is, until the cost of computing and data communication equipment fell by orders of magnitude during the late 1970s and early 1980s. This decline in the cost of supervisory systems, coupled with the availability of CNC (Computer Numeric Control) work centers and robotic arms, began a radical change in the way the factory would be run. Not on-

ly did the availability of such systems make change economically attractive, but also fierce international competition for manufacturing markets made it mandatory. Central to this information intensive new manufacturing organization is a concept referred to as JIT manufacturing.

JIT inventory control is a concept that has spread rapidly through the manufacturing sector during the past few years. The single credo of the JIT philosophy is "Inventory is Evil." In the JIT environment, suppliers are not asked to bid competitively for large single orders, but rather, orders are negotiated months ahead on a weekly or biweekly schedule. The supplier can thus better predict his work load for the coming months and avoid being caught with unwanted inventory of his own. Changes in demand or problems with quality control may cause shortages, so the supplier is usually required to carry a small reserve. Still, both parties in such an agreement are able to greatly reduce the amount of inventory that must be stockpiled. The cost per item is often lower than it was under the old "big order" system, and the capital tied up in inventory is greatly reduced.

The JIT system affects not only the supply end of the manufacturing system; it affects every process and level within the plant. In an ultimate implementation of JIT manufacturing, computers would track every single screw, quart of paint, and welding rod. New orders, and materials expended, are reflected in the inventory requirement projections within seconds of

their occurrence. An engineer would call this a "closed-loop system," and it is enormously efficient and responsive.

The JIT environment is by its very nature a place of great order and it is not surprising that the JIT system works best in automated operations. One of the most serious problems encountered in implementing such a system is the transport of work in process (WIP). If parts are allowed to pile up at a work cell until there are enough to form a unit load, a pallet for a conventional AGV, the credo of JIT has already been violated. Additionally, standard AGVs usually require fairly wide pathways and wide sweeping turns, a very wasteful use of space. On the other hand, if humans are used to move the work in process, they often neglect to properly inform the host computer of the actions that they have taken and order is lost.

There are alternative means of moving WIP. For example, robotic arms can be formed into clusters and "bucket brigades," with each arm passing work to the next. This configuration is weak in that a single robot's failure can stop the line. Alternatively, arms can be placed on either side of a conveyor belt, with the WIP moving

down the conveyor from station to station. This solution is frequently acceptable, but it too can present problems. Conveyor belts have a lot of moving parts, and if they fail the whole line stops. Also, a conveyor is basically a one-dimensional transporter, and it can interfere with the use of floor space. Finally, a conveyor system is not flexible, in that its path can not be reprogrammed in software.

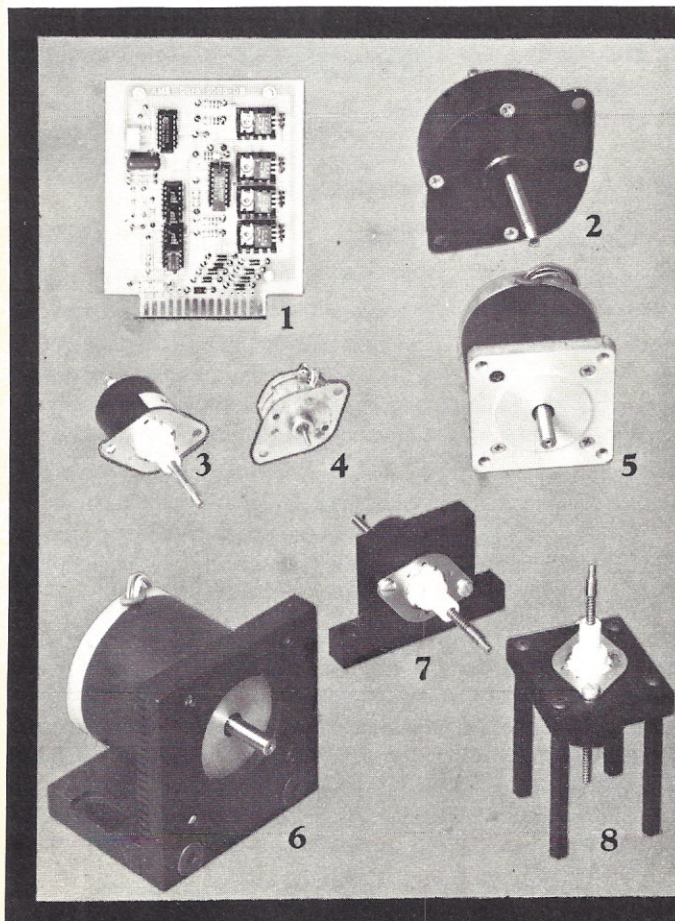
THE AGILE AUTONOMOUS VEHICLE SOLUTION

What is needed, then, is a flexible X-Y conveyor, and that is precisely what an AAV is. The distinguishing characteristics of an AAV are:

- A zero turning radius and high degree of maneuverability
- A narrower and higher profile than an AGV
- Virtual (as opposed to physical) path control and advanced, redundant, navigation systems
- A higher level of on-board intelligence
- Enhanced sensory capabilities for navigation and collision avoidance
- Ability to self-load and unload

- Enhanced communications with the host computer and with the fixed equipment with which it must dock
- Lighter payloads, typically less than 50 lbs, but up to perhaps 250 lbs
- A more intelligent host computer system, and tighter interaction with other equipment in the plant

Since the floor space between machines is at a premium, it makes sense that the pathways used by an AAV be as narrow as possible. This requires a more maneuverable vehicle, one with better sensory capabilities, and necessitates a smarter host computer as well. Better sensory capability is needed to prevent collisions with nearby machinery and/or people in the narrower aisles. There is also an increased likelihood of traffic jams resulting from several vehicles using the same pathway in conflicting directions. Improved traffic planning and arbitration by the host computer can reduce these potential problems significantly. Thus, an AAV must know its position much more accurately than is typical for an AGV, and must provide this information to the host computer when requested.



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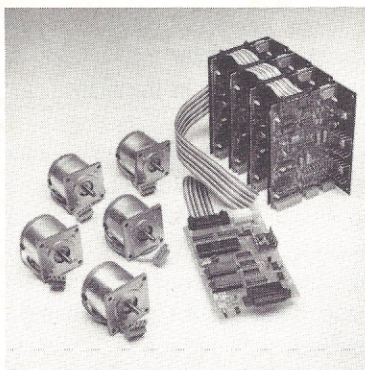


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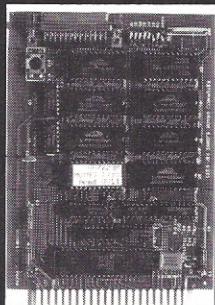
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If the vehicle is to have a minimal turning radius, it must be more or less round in its horizontal silhouette. This, combined with the fact that it must have a narrow clearance, dictates a fairly small base geometry. The vehicle will therefore tend to have a higher profile, since this is the dimension in which it is least restricted. As it turns out, this configuration is appropriate for the AAV, because it is going to be interfacing with equipment originally designed for human interaction. Since most AAV loads will be less than 50 lbs, the vertical stability of the vehicle can be quite good if its center of gravity is kept low. The Cybermation approach has been to build a generic platform module and to combine it with different upper modules and support firmware to form "vertically integrated" vehicles. One of the primary design considerations for the K2A platform was to get the batteries, gear box, and drive motor as low as possible (Photos 1 and 2).

Most AAVs will have a more sophisticated navigation system than AGVs normally require. The reason is that the number of paths will be much larger, and the frequency with which the paths must be redefined will be higher (due to changes in floor space use). The use of "virtual paths" will become very attractive. In a virtual path system, the vehicle has a path defined in software which can be transmitted to it as required. Virtual paths can be defined using natural references or special navigational references. Humans navigate using natural references, such as the relationships of walls and objects to the desired path, and eventually automatic vehicles will be able to do this. The process of mapping natural references requires very good sensory capabilities and a high computational overhead. Mapping is therefore unlikely to become the dominant means of navigation in AAV applications for some time.

By introducing easily identified references into the environment, both the sensory and computational requirements of the vehicle can be significantly reduced. Such references can be passive devices, such as reflective bar graphs, or active devices, such as infrared (IR) beacons. It is preferable that the vehicle be able to gain more information about the reference than just its relative direction. The Cybermation navigation system, for example, fills the area with a structure of light by which

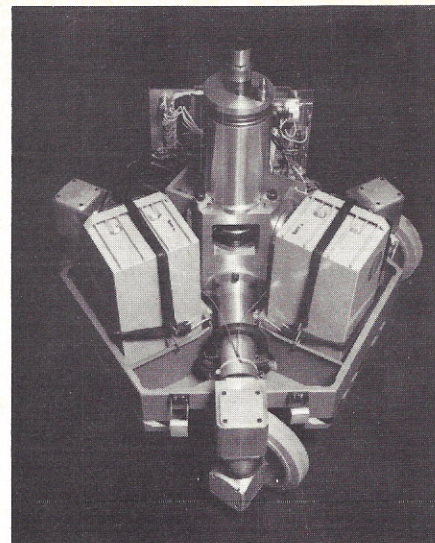


Photo 1. The K2A platform is shown with its cover removed. One primary design consideration was to position the batteries, gear box, and drive motor as low as possible.

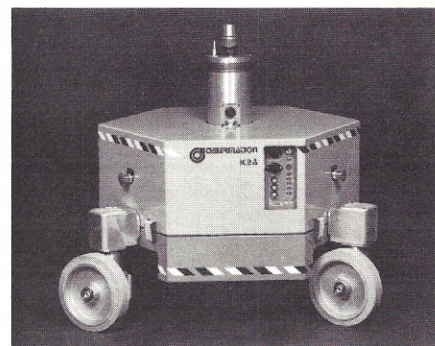


Photo 2. The K2A Agile Autonomous Vehicle is built on a generic platform module and combined with different upper modules and support firmware to form "vertically integrated" vehicles.

a vehicle can determine its absolute position within a few inches. The IR navigation signal also contains high-speed data from the host computer, and data can be sent back from the vehicles as required.

With a conventional wire-following system, the vehicle has a continuous indication that it is on the path. Virtual path systems are, on the other hand, subject to frequent interruptions and even occasional erroneous indications. It is therefore necessary for an AAV using a virtual path navigation system to have excellent dead reckoning navigational capabilities and enough on-board intelligence to navigate through these periods of imperfect position data. Thus, if the vehicle has a carriage system that seldom slips or turns due to poor traction, and if the sensory system is capable of tracking nearby features, a weighting algorithm can be used to correlate the good data out of the conflicting

background of data, and to navigate without interruption.

It was with all of these qualities in mind that Cybermation developed the K2A Mobile Platform. Although the company is offering several vertically integrated configurations of the vehicle, including the K2SRV (Standard Research Vehicle) for other groups doing navigational research, the flagship configuration has always been intended to be the K2AAV. The K2AAV vehicle consists of a K2A platform, a static payload bay, and an application turret with a lift mechanism. Except for the absence of the lift and navigation system, the K2AAV will look exactly like the K2SRV (Photo 3).

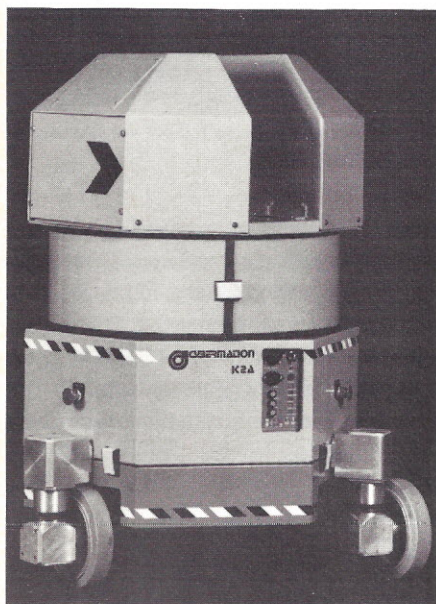


Photo 3. The K2SRV (Standard Research Vehicle) is being offered to various groups involved in navigation research.

To provide the required dead reckoning accuracy, the K2A uses direct shaft drive for both the steering and the drive of all three wheels. This configuration is referred to as Synchro-Drive, and it causes the wheels to steer parallel at all times (for reference, see "Rethinking Robot Mobility," John M. Holland, *Robotics Age*, December 1984). Additionally, all of the wheels are driven in lock. A specially designed, low backlash reducer is used in the steering to further improve accuracy. To understand the advantage of this configuration, consider the case of the front wheel drive tricycle system common in many AGVs. When poor traction is encountered, the single driven wheel is very likely to slip. Worse yet, when the vehicle is climbing a grade the weight is shifted away from the driven wheel and traction

is very poor (Figure 1). For a wire-following system this may be acceptable but for an AAV it can be real trouble. To make matters worse, the AAV is much more likely to encounter bad traction due to hydraulic fluid spillage, sawdust, metal shavings, and other substances common around the machines it must service.

The nature of Synchro-Drive provides that the force vectors of all three wheels remain parallel; there is thus no tendency of irregular traction to cause the vehicle to rotate. Rotational slippage is more important than longitudinal slippage, as it causes a continually increasing positional error as the vehicle travels.

The final reason that Synchro-Drive is so well suited to AAV type vehicles is that it provides for a zero turning radius and a very rapid turning rate. When a Synchro-Drive vehicle executes a turn, only the wheels and the turret rotate. A Synchro-Drive AAV can drive into a dock, pick up a tote or tray, turn 180 degrees, and drive out. Since the heavy base does not have to be rotated, the K2A can turn at a rate greater than 120 degrees per second. Considering that the pathways an AAV must follow will often be narrow and have many turns, this feature is particularly appealing.

Cybermation recently performed a series of tests on the first of its production model K2A platforms. The vehicle was given a dead reckoning path to follow consisting

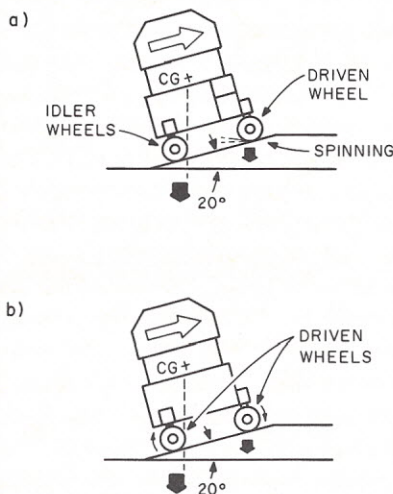
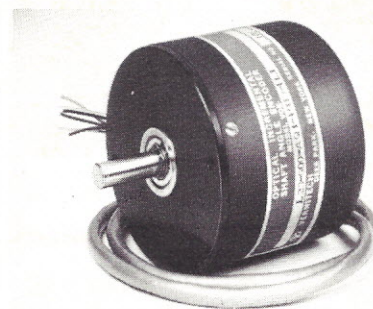


Figure 1. Traditional front wheel drive tricycle systems such as that shown in 1a tend to slip when they encounter poor traction. Also, when the vehicle climbs a grade the weight is shifted off the driven wheel. The wheels of the Synchro-Drive AAV, shown in 1b, are driven in lock and are always parallel. Irregular traction is therefore not likely to cause the vehicle to rotate. Furthermore, on a grade the weight remains on wheels under power.



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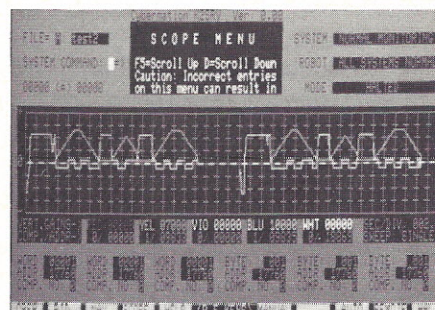
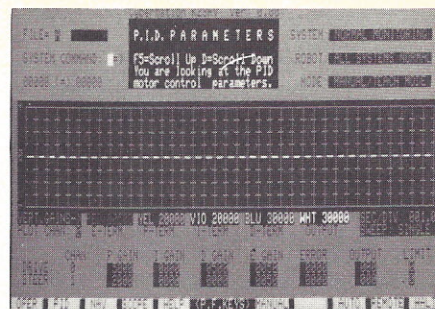
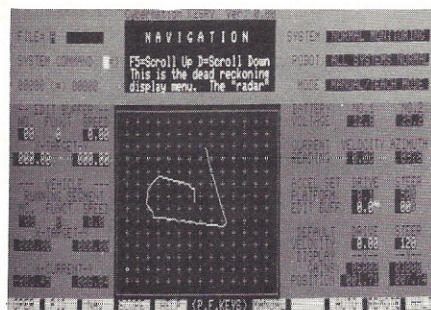
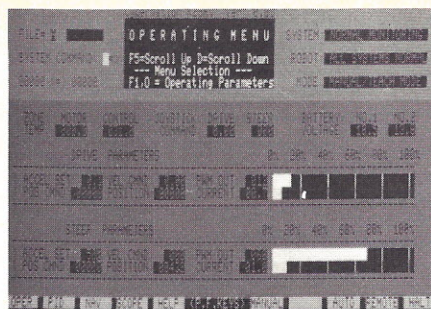


Photo 4. The oscilloscope displays appearing in the computer menus used in the K2SRV are for research purposes only and will not be retained in the final AAV configuration.

of a Figure 8 pattern with 12 turns and a docking maneuver, covering approximately 100 ft. At the end of the maneuver, the vehicle was instructed to return to its starting position and the position error was checked. The test was repeated 20 times, and the worst terminal position error was 6.2 in., with an average error of 3.9 in.

The vehicle was configured as a K2SRV and was later delivered to General Motors Research. The body of the SRV is identical to that of the AAV, except that the AAV will have a lift mechanism in the turret slot. Also, the navigation system will be mounted above the turret. The host computer menus used in the SRV configuration are shown in Photo 4. The scope displays are strictly for research purposes, and will not be retained in the AAV. Instead, the K2AAV will have task scheduling menus.

Cybermation is currently building a number of K2A-based vehicles, including the first K2AAV. This first AAV is being developed under contract with a major corporation (not General Motors) to demonstrate the AAV concept. As part of this demonstration, the K2AAV will move trays of parts among various destinations, and will travel through narrow aisles and doorways.

CONCLUSIONS

The escalation of manufacturing competition on a worldwide level and rapid ad-

vances in technology are driving manufacturers to adopt automation and computer control at a very fast pace. In this environment there is an increasing demand for systems that can move relatively small quantities of work in process rapidly and to a diverse set of destinations. One of the best solutions to this need is a highly maneuverable vehicle which we have dubbed an AAV or Agile Autonomous Vehicle.

None of the hardware or software required to produce a reliable AAV system is beyond today's technology. In fact, the systems required do not even represent high technology, but rather the fusion of proven technologies from several different disciplines. Although self-navigating vehicles (sometimes called mobile robots) are being developed for a wide variety of tasks (including everything from security applications to waiting tables), the AAV system is likely to be one of the first places in which such vehicles prove to be economically justified.

John M. Holland is president of Cybermation Inc. and author of *Basic Robotics Concepts* and *Advanced 6502 Interfacing*.

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ROBOTICS IN THE NAVY

Part II: Nonindustrial Development Efforts

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Washington, DC 20362

This is Part 2 of a two-part article. Part 1, which appeared in the November 1985 Robotics Age, examined special adaptations of industrial robots as required by the very large size of Navy ships and the relatively small number built in a year. Welding, cutting, and measurement operations were among the robotic applications discussed.

Among other Small Business Innovative Research Programs projects being managed by the Naval Surface Weapons Center (NSWC) is a study by Odetics Corporation of potentially hazardous operations aboard Navy ships that could be addressed by automation. Initial emphasis is being placed on shipboard firefighting, ordnance handling, and damage control. The most advantageous types of motion effectors, as well as required sensors, are being identified in an attempt to better understand the issues associated with shipboard implementations.

Problems associated with such applications in general are complex, and a limited awareness of what is technically feasible, combined with reliability and maintainability concerns in at-sea environments, has hampered attempts to come to grips with these issues. A study by Sharon Hogge of NSWC aimed at identifying potential robotic applications for ships now in

design produced the following list of possibilities:

- Cleaning—propeller (underwater), hull (underwater), tank and void, bilge and tile
- Coating and preservation—non-skid application, paint chipping, wire brushing, painting, application of flame-sprayed coatings
- Industrial—shop-based welding/cutting, nuclear maintenance, electronic testing and calibration, valve maintenance work cells, inspection/quality control
- Damage control—mobile NBC sniffer for damage control assessment, firefighting systems, explosive ordnance disposal
- Security/watch—watch standing, intelligent sentry, security applications
- Material handling—underway replenishment applications, weapons handling, material handling in NBC environment, intelligent fork lifts
- Undersea applications—mapping and charting, mine placement and recovery/neutralization, undersea search and recovery

Results that have been validated through a meaningful evaluation process cannot be expected for some time, and such evaluations may very well prove that many of these are not viable robotic applications

and should not be pursued. Others may have good long-range potential, but an unfavorable technology prognosis for the near term.

The perceived lack of appropriate technology has been generally responsible for the prevailing feeling that shipboard applications are for the most part premature. However, the past few years have shown a phenomenal increase in technological development, accelerated by national incentives such as the \$600 million Strategic Computing Program of the Defense Advanced Research Projects Agency. The impact on the Navy of this technological growth is the ever-increasing probability that many robotics applications will become technically feasible within the next ten years. It is only through active involvement that Navy researchers can stay abreast of the rapidly emerging developments and match application needs to actual capabilities.

Numerous efforts aimed at correcting some of the identified deficiencies associated with applications requiring system mobility have thus ensued throughout the Navy laboratories. An example of a general purpose research tool is ROBART II ("A Second Generation Autonomous Sentry Robot," *Robotics Age*, March 1985). This sophisticated development platform employs a control

hierarchy of eight on-board microprocessors and a multitude of ranging and proximity sensors for environmental awareness. The robot was used to acquire real-world data in support of some excellent research addressing the use of redundant sensors for mobile robot navigation. This work was done by Anita Flynn while working as a co-op student at NSWC in pursuit of her master's degree at the Massachusetts Institute of Technology. The prototype is often used by the laboratory as a test bed for mobile robot research and sensor evaluation. Test results have been quite valuable to the Navy in providing technical support for a tri-service exploratory research program managed by the Defense Nuclear Agency, which is investigating the use of robotics in physical security.

Among the major problems associated with mobile robot development is collision avoidance. The system must be provided with enough information about its environment so it will not run into surrounding objects as it moves around. The problems associated with the detection and geometric resolution of obstructions are two fold: collecting high resolution three-dimensional data describing the environment, and processing and interpreting that data. Severe technological deficiencies that seriously hinder the development of truly autonomous mobile robots exist in both areas.

In recognition of these needs, a project was initiated at NSWC to build a passive, three-dimensional vision system that would be especially well suited for use on a mobile platform. A prototype single lens camera with special reconfigurable, wide-aperture optics was designed and constructed in 1984. Its extremely narrow depth of field can be used to effectively isolate objects of interest in the scene being viewed from background and foreground clutter. A motorized lens focusing system is employed to slew the focus back and forth throughout the range of interest to obtain a frame rate approaching 30 Hz. In this fashion, successive two-dimensional "slices" are used to build up a three-dimensional model of the scene.

Much image processing, including feature extraction and clutter rejection, is performed instantaneously by glass optics and analog electronics to greatly reduce that required in later digital stages. Unwanted details such as objects in the

background can, in essence, be filtered out simply by not allowing the system to focus on them. For example, in a collision avoidance mode the robot may be concerned only with objects that come within ten feet, and so the optics are configured

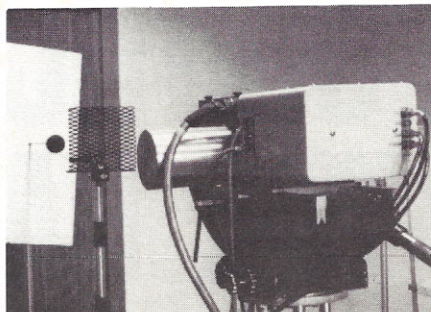


Photo 1. In the prototype passive 3-D vision system developed by the Naval Surface Weapons Center (NSWC), the narrow depth of field associated with the wide-aperture optics allows the sensor to see through the expanded metal screen in the foreground and capture high-resolution data describing the sphere without detecting the background clutter simulated by the textured tile square. (Photo courtesy of NSWC.)

under computer control to produce an effective scan over the range of one to ten feet out from the unit. The scene details beyond that range are never captured by the sensor, and therefore do not have to be isolated from the objects of interest by the image processing software.

The range resolution of the prototype is calculated to be the effective sensor depth of field divided by 1000. The reconfigurable nature of the optics allows for sweeping considerable distances with rather coarse resolution, and then readjusting the scanned range for high resolution data-gathering in the local vicinity of a point of interest once detected. Initial test results of the sensor have been highly encouraging (Photo 1). A completed first generation system is scheduled for demonstration on a prototype low-silhouette robotic battle vehicle test bed also under development at NSWC.

The 3-D Vision System is a joint venture among Associates and Ferren of Easthampton, New York, the University of Cincinnati's Vision Laboratory, and NSWC. Associates and Ferren is building the optical preprocessor, the University of Cincinnati is assisting in the image processing task, and NSWC is developing an image understanding expert system and performing overall systems integration. As

mentioned in Part 1 of this article, a modified version of this concept is planned for incorporation into the Integrated Flexible Welding System as a global vision system for viewing the entire working envelope of the welding robot.

Considerable emphasis has been placed upon the investigation of robotic systems for hazardous operations such as fire-fighting and explosive ordnance disposal (EOD). Initial efforts in these areas have begun more as teleoperated or remotely controlled devices, with the operator providing all of the system intelligence. As advances are made in the supporting technologies, there will be a natural trend in these developments towards more system autonomy, with the human retained in the control loop for high-level decision making and oversight functions.

A remotely controlled hose delivery system designed and built by a development team at NSWC headed by Mary Lacey is shown undergoing testing in Photo 2. The base platform is a modified hydrostatic drive front-end loader powered by an internal combustion engine and equipped with a trainable nozzle. All vehicle and nozzle functions are controlled by an operator using a handheld control station up to 500 feet away. Advance development efforts now under way will pursue an all-electric tracked vehicle with a fiber-optic control link, capable of speeds up to 10 mph.

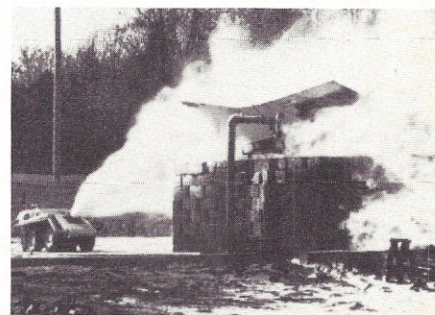


Photo 2. A prototype teleoperated firefighting system is undergoing testing by the Robotics Research and Development Laboratory at NSWC. (Photo courtesy of NSWC.)

The majority of development work for EOD applications has been managed by John Butler of the Navy Explosive Ordnance Disposal Technical Center in Indian Head, Maryland. Prototype systems have been built to inspect and perform a limited number of remote operations on live ord-

nance in an attempt to minimize exposure of personnel. ROVER (Remotely Operated Vehicle for Emplacement and Reconnaissance) is a tethered mobile platform equipped with a closed circuit television camera. The vehicle employs an electrically powered highly maneuverable tracked drive system and features a 3 degree-of-freedom manipulator for gripping objects. SAMSON (Semi-Autonomous Mobile System for Ordnance Neutralization) is similar in nature with a 6 degree-of-freedom manipulator, tool changing capability, and planned enhancements of on-board sensory capability.

HERC (Heavy Equipment Remote Control) is a general purpose remote control capability that was built for field installation on a variety of conventional heavy equipment. It has been tested on eight vehicle classes including backhoes and tanks. The initial objective was to provide such equipment with a teleoperated mode of control to improve the safety of personnel involved in clearing firing and testing ranges, but the concept can be easily extended to other types of applications. The low-cost HERC kit can be installed in just a few hours and is an excellent example of optimal use of available technology to address an operational need.

The underwater arena offers perhaps the most favorable environment for near-term employment of autonomous systems, and quite obviously is of great interest to the Navy. Problems associated with collision avoidance and terrain traversability which plague land-based mobile system development are relatively non-existent in the more structured undersea environment. At the higher operating frequencies possible with water as the conducting medium, sonar systems provide much better scene resolution than can be achieved with

ultrasonic ranging systems operating in air. For these and other reasons, underwater applications are being seriously evaluated for opportunities to apply available robotic technology.

ADROV (Advanced Development Remotely Operated Vehicle) is being designed and built for NAVSEA at Indian Head to allow remote inspection of underwater objects by divers on the surface. The system receives electrical power for propulsion over a tether from a dedicated 30-foot support boat, and is equipped with an

underwater video camera and sonar array.

A free-swimming vehicle (Photo 3) was constructed at the Naval Ocean Systems Center (NOSC) in San Diego, California, as a designated research test bed for autonomous or tele operated underwater search and inspection tasks. The unit is equipped with sonar, a video camera, a magnetic compass for navigation, and an altimeter for depth control. In the teleoperated mode the vehicle communicates with the operator via a fiber-optic link, receiving commands during the

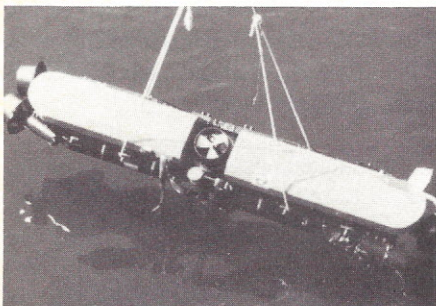
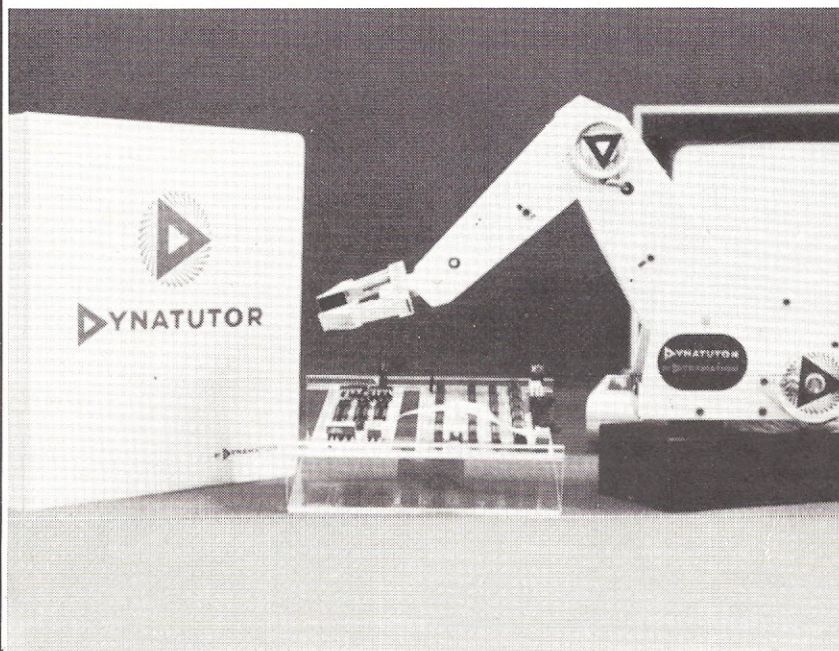


Photo 3. An autonomous free-swimming vehicle is being developed by the Naval Ocean Systems Center (NOSC) as a research test bed for underwater applications. (Photo courtesy of NOSC.)

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retrace portion of the video signal being sent to a surface monitor. When tethered in this fashion, a special underwater manipulator can be added, controlled by operator voice commands.

Probably the most advanced nonindustrial research effort now underway is a project directed by Scott Harmon at NOSC. The Ground Surveillance Robot (GSR) is intended to develop and demonstrate autonomous systems technology for U.S. Marine Corps applications. This mobile robot, shown in Photo 4, is built upon an M114 armored personnel carrier. Originally designed for surveillance and command and control missions, it was retired from service in the late 1960s. The vehicle currently weighs 15,000 lbs, is powered by an 8-cylinder gasoline engine, and employs an automatic transmission with skid steering (i.e., either track can be differentially braked). All control functions of the vehicle have been adapted for interface to the locomotion computer.

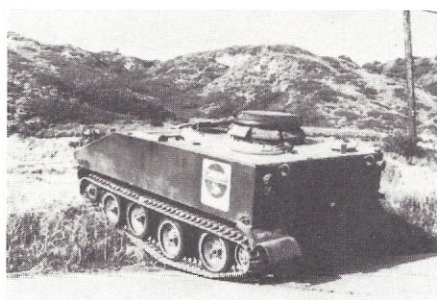


Photo 4. The Ground Surveillance Robot under development for the Marine Corps is undergoing preliminary testing at NOSC. (Photo courtesy of NOSC.)

The GSR has 15 on-board microprocessor units (8086s) and approximately 8.5 Mbytes of RAM. The specially developed architecture completely distributes control to the robot's subsystems, making them equal partners in achieving the vehicle's goals. All such distributed subsystems exchange information through a blackboard mechanism, and are connected to the network through intelligent interfaces. These mediate communication of plans (control information) as well as reports (system state information), while providing a standardized interface between system sub-components.

The GSR is equipped with roll and pitch angle sensors for monitoring vehicle attitude, and a true ground speed sensor based on CW radar doppler. The naviga-

tional subsystem includes a satellite navigation receiver, a track speed counter, a flux gate magnetic compass, and a gyrocompass with magnetic update. An acoustic proximity sensor subsystem uses four transducers that can be rotated about the vertical axis, and three fixed units that look directly in front of the vehicle. A vision system currently consisting of a single high-resolution CCD camera is mounted on a computer-controlled transport platform having pan, tilt, and vertical extension motions. Using this preliminary configuration, the GSR is able to autonomously follow another vehicle in the midst of surrounding obstacles, effectively demonstrating the real-time integration of both vision and acoustic sensory information.

Next year, a laser rangefinder will be fitted to the GSR, mounted close to the camera on the vision transport mechanism. The rangefinder's beam will be steered in two dimensions by a mirror under computer control. This combination of camera and rangefinder will enable the GSR to accurately model surrounding terrain features. The vehicle will be demonstrated traversing a simple obstacle-filled area using vision, the laser rangefinder, and proximity sensors. The final addition of a global planning system will prepare the GSR for its ultimate goal of autonomous transit over unknown natural terrain. As a research platform, the GSR is meant to further contribute to autonomous systems technology by demonstrating a valuable generic capability (i.e., autonomous transit). Actual missions for military vehicles that might result from this effort are not yet specified.

SUMMARY

None of the work described herein or in Part 1 of this article is finished, and it will be some time before we are able to measure with assurance just how beneficial robotics will become to the Navy of the future. But the prognosis—based on what we have accomplished thus far and what we have learned in the process—is certainly encouraging.

It seems evident that robotics can be successfully applied to small batch processes associated with ship and weapons system manufacturing. The main thrust of the remaining efforts will be to make conventional systems intelligent enough to accept off-line CAD input for initial program-

ming, responding adaptively to on-line sensor data describing changes in workpiece configuration and process parameters.

Success in these areas will open the door to even greater payoffs in maintenance and repair. Here may be seen a potential that is virtually limitless insofar as the existence of opportunities is concerned, because the requirement for maintenance and repair will continue—and, in fact, accelerate—long after the fleet achieves its projected size of 600 ships in 1990.

Shipboard robotics applications are today a long way from reality due to technological deficiencies in the areas of required sensors, computational resources, motion effectors, and energy sources. Future research must address the issues of operability and maintainability in the harsh demands of an at-sea environment, but the perceived potential to alleviate manpower shortages will remain a strong driving force for these efforts. Teleoperated devices developed for hazardous duty applications will eventually evolve into semiautonomous and autonomous platforms as technological advances provide for more system intelligence.

To appreciate just how profound a change all this may precipitate, one must envision a plot of the exponential growth rate of such sophisticated technology versus time, extrapolate out to 1990, and ask the questions, "What type of capabilities should we expect to see?" and "How can we prepare for them now?" This becomes very important, considering that the acquisition cycle for a ship is roughly fourteen years. A backward glance at trends over the past few years yields awesome visions of the sophistication we can expect to achieve in the next fourteen. By steering this technological growth toward Navy needs, and by incorporating minor changes into the design process, the Naval Sea Systems Command attempts to ensure that ships' systems will be compatible with the robotic technology of the future that quite obviously awaits them.

LCDR H.R. Everett is the director of the Office of Robotics and Autonomous Systems, Naval Sea Systems Command.

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MINI ONE: AN AGV PROTOTYPE

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Many advanced computer controlled technologies are emerging in the automated factory due to the heavy demand placed on flexible automation. New methods and systems are constantly being developed to implement the conceptual factory of the future. One of the largest areas of growth in industrial automation is in materials handling. One technology contributing to this growth is the automatic guided vehicle system (AGVS). An AGVS can be defined as an unmanned vehicle capable of receiving an external guidance signal to deliver a load from one point to another via a predetermined track. AGVSs are extremely flexible in application and function because of the many different vehicle configurations and intelligence levels available. AGVSs are numerous in industrial settings, transporting materials in warehouses, factories, mills, and limitless other industrial and commercial applications.

As AGVS technology develops, an understanding of the device's internal workings becomes more and more important. One problem does arise though: where can you find an industrial AGV to disassemble and examine? The only alter-

native to purchasing an AGV is to build one. The Mini One (Photo 1) was conceived of and constructed as a student project at Piedmont Technical College in Greenwood, South Carolina.

The industrial wireguided vehicle was used as a model for the Mini One, and some of its capabilities were incorporated into the design:

- The vehicle must track a current in a wire path loop that would guide it to its destination.
- It must be able to sense an object in its path, stop, and sound a warning.
- It must have a compact CPU to receive data and make decisions.
- It must display its basic components and be expandable for further capabilities.
- It must not carry a state-of-the-art price tag.

With these goals in mind, components and parts were sought from surplus equipment houses and old components were salvaged from the scrap pile. The sources of parts and components are listed at the end of this article.

CHASSIS DESIGN

The chassis of the Mini One was constructed from an Automat 2000 kit, which is an industrial version of an erector set that includes an assortment of guiders and connectors. The kit was used also to construct the main drive hub, a subassembly in the front of the vehicle. The Mini One employs a tricycle design in which the drive hub controls steering and drive and the base rides on top. The drive hub assembly uses a machined aluminum plate as a base

to support a high torque gear motor. The drive hub is also connected to another high torque gear motor that controls steering via a chain and sprocket drive at a 2:1 ratio. The gears and chain were also part of the kit.

The chassis houses all the electronic circuit boards that control the Mini One: a Mini 73 computer, an ultrasonic ranging system, a guidance circuit, an interface expansion board, and a horn driver circuit. The boards are all on top of the vehicle and are easily accessible. The chassis also holds four 6-V rechargeable gel cell batteries. The transducer from the Polaroid ultrasonic ranging system (URS) is mounted on the front head panel, which also houses a piezo horn. The two rear wheels are free-spinning. Their chassis supports are reinforced to carry the 8 lbs. of batteries.

ELECTRICAL, ELECTRONIC, COMPUTER, AND SENSOR DESIGN

The on-board electronics are divided into two systems: guidance tracking and obstacle detection. The guidance circuit consists of an array of operational amplifiers. It uses two inductors, surplus solenoid coils, to follow the path of the current, approximately 1 amp (Figure 1). When the Mini One is moving, the guidance circuit readjusts the drive hub by powering the steering motor, thus keeping the wire centered between the sensors. When one of the sensors drifts toward the wire track, a current is generated and amplified. The operational amplifiers boost the signals and feed them to a differential amplifier, where the stronger of the two signals is

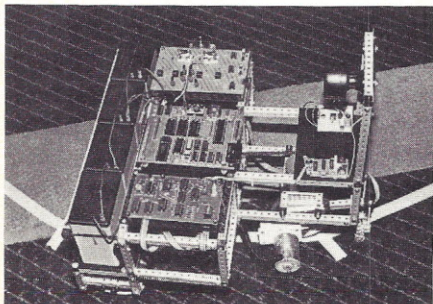


Photo 1. The Mini One AGV prototype is based on the industrial wire-guided vehicle.

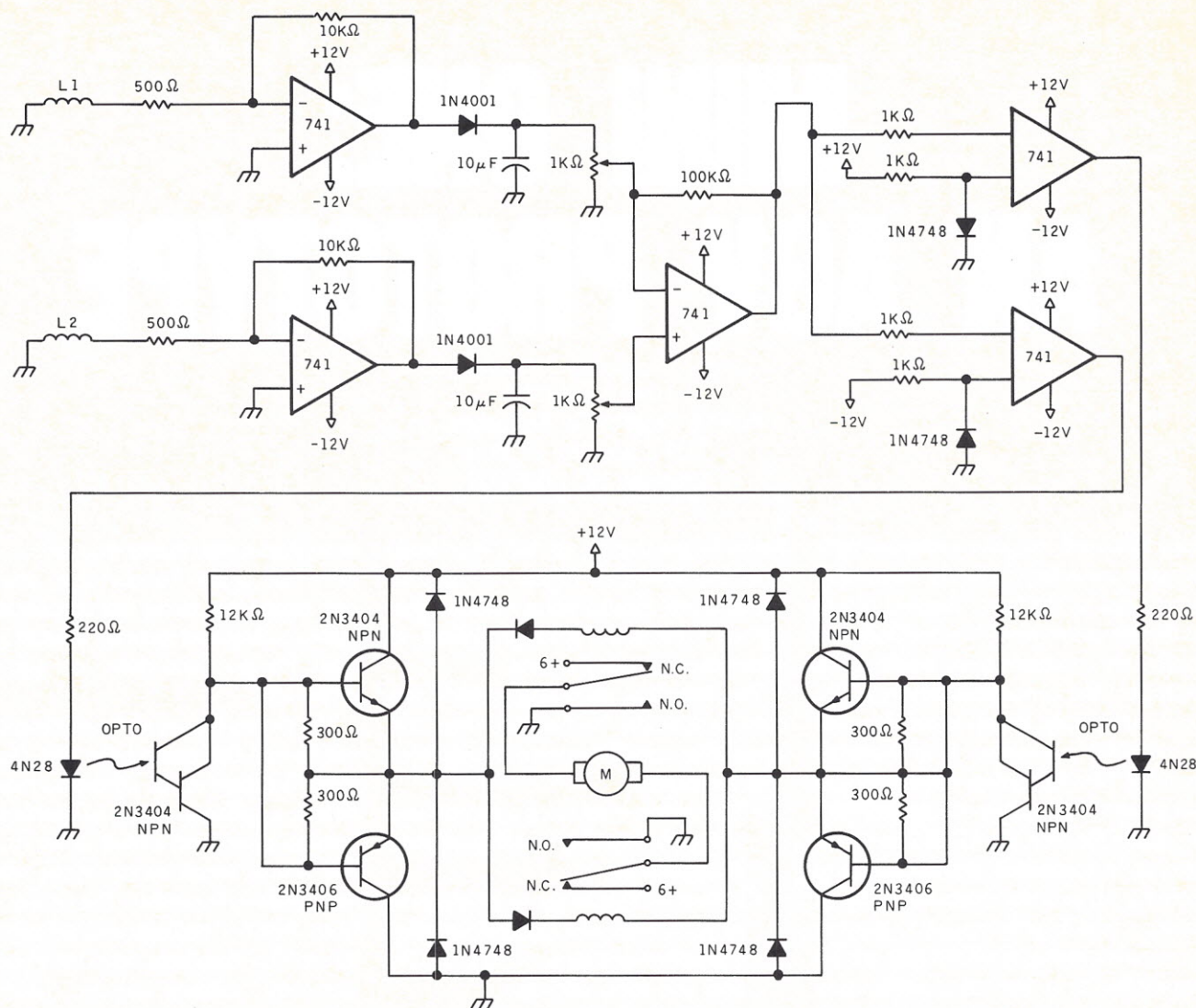


Figure 1. The AGV's guidance circuit is shown.

output to two comparator amplifiers. The comparators configure the direction of the power switching transistors that control the direction of the drive motor. When one comparator goes high, it creates a pathway for current in a particular direction. If the other comparator goes high, the pathway configuration is opposite and current flows in the opposite direction. This allows the Mini One to maintain servo steering control. The guidance circuit constantly monitors the inductors for a signal to guide the drive hub via the sprocket and chain drive.

The on-board processor is an 8073 with a BASIC interpreter; it is also the MPU for the Mini 73 computer. The Mini 73 is a versatile compact microcomputer with built-in BASIC. The computer has 2 K of

Listing 1. Mini BASIC Control Program

Let X=144	Initialize PIA
Let X=@# F003	Store control word at data direction register
10 @#F001=#00	All outputs zero
20 Let A=@#F000	Assigns Port A to A variable
30 If A<5 THEN GOTO 50	Distance decision
40 GOTO 10	
50 @#F001=03	Enable and disable horn driver
60 DELAY	Waits for obstruction to move
70 DELAY	
80 GOTO 10	Returns to monitoring distances



RAM memory, an 8255 PIA, an EPROM burner, and a battery back-up memory. The program that controls the Mini One's obstacle detection is depicted in Listing 1 and is in mini BASIC.

The Mini 73 is interfaced to the URS, a sonar distance detector that transmits and receives a "chirp" which is used to calculate the time/distance interval. The system displays the distance in feet and tenths of a foot via a set of multiplexed data lines. The interface between the URS and the Mini One occurs at these data lines, which run between an MC14553 three-digit BCD counter and an MC 14543 decoder driver. The code from the four data lines of the URS must first be demultiplexed, and distance select lines 1 and 2 must be held by a CMOS latch circuit.

The data, in 8, 4, 2, 1, BCD code is buffered from CMOS to TTL levels. The Mini 73 receives the parallel data through the 8255 PIA parallel port. The Mini 73's program monitors the distances received, and interrupts forward movement if an object closer than 5 ft. is detected. When an obstacle is sensed, the computer sends a

signal to a normally closed contact that stops the drive motor and another signal is sent to the horn driver. The Mini 73, after a short delay, rechecks the distances and restarts the drive motor if the path is clear.

The Mini 73 was interfaced to the URS by adapting a circuit published in Polaroid's URS Handbook application notes and technical papers. The circuit used in this application is shown in Figure 2.

CONCLUSION

The Mini One prototype has been a success in introducing students to basic AGV principles. The obstacle detection circuit was the only problematical part of the project, and through trial and error the latch circuit was eventually perfected. The Mini One won the 1985 South Carolina Technical School competition and was featured on "PM Magazine." The design and construction of the Mini One laid the groundwork for the implementation of an industrial-grade wire guided vehicle at Piedmont Technical College.

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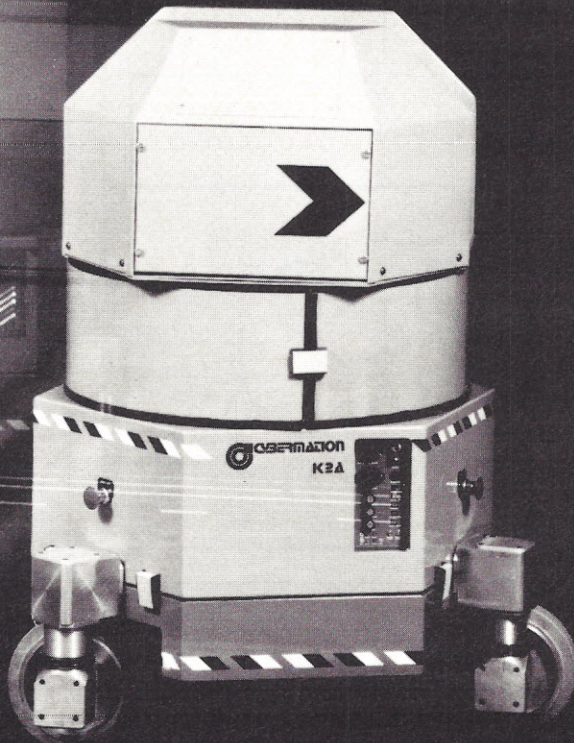
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SIMULATION ON THE SEE WHY SYSTEM

Deciding whether to implement an automated system and thinking through the changes that automation involves are among the greatest challenges manufacturing management faces today. The number of variables that must be taken into account to effect a smoothly running system, along with the current lack of firm design rules for automation, can lead to costly trial-and-error experimentation on the factory floor.

To avoid bottlenecks, stoppages, and overexpenditure on capital equipment, an automated system should be simulated before it is implemented. The risks associated with starting a program can in this way be greatly reduced and operational problems occurring after start up can be solved more readily. Simulation tools are not new to engineers. Still, there are recent advances in simulation technology that offer a number of advantages over prior systems. One new approach uses an animated visual interactive simulation system. Two case histories will illustrate the reasons two companies chose to use See Why, a simulation system developed and marketed by Istel, Inc. of Burlington, Massachusetts.

The first is that of the NCR Corporation's Wichita, Kansas, facility. The firm makes business computers, computer peripherals, and subsystems. The very first model built at NCR using See Why led to an initial savings of \$200,000. Simulation revealed it was not necessary to add a conveyor system.

The second case history involves an automotive plant where a potential production loss and a delay in launching a new automobile was avoided. See Why identified and corrected the logic in a computerized network. Significant savings were achieved in that plant as well.

According to Richard Deaver, Consultant Engineer in Automation at NCR Wichita, the Engineering and Manufactur-

ing Group began studies in automation late in 1982. The purpose of the studies was to determine how automation could be used to reduce costs and improve productivity. A simulation language used by NCR in a prior study of aircraft control systems was found to be inadequate for the group's purposes. See Why was chosen after a review of several alternative systems. An evaluation of the traditional GPSS language revealed to management that the printed output was difficult to interpret and that it was too hard to learn. The Engineering and Manufacturing Group finished its search by identifying a number of features it found desirable and available in the See Why system. They included:

- Animated color graphics
- User friendliness
- Operator interactive capabilities
- Model preloading
- High-level language programming
- Both discrete event and continuous process modeling
- Statistical data gathering and analysis
- Off-the-shelf hardware
- High flexibility and versatility
- Large subroutine library for use in writing models
- Large installed customer base

The first NCR application for See Why was in a printed circuit board test area.

When the system was delivered, NCR was in the middle of a drive to greatly reduce inventory and to implement a Just In Time program. The engineers had thought that to achieve these goals an automated conveyor system would be needed to deliver tote boxes of boards to various test operations. A simulation model was built, based on the vendor's conveyor operating specifications, a description of the test process, and the routing and standard number of hours per board. Even though this was the first model NCR built, it was finished in eight weeks.

The model made full use of See Why's capabilities for animated graphical display, operator interaction, and statistical analysis. The graphics allowed NCR's engineers to see the movement of materials to and from more than 40 work stations and testers. Data on throughput, workstation and conveyor use, and test times was collected, analyzed, and displayed while the model was running. Meanwhile, the Test Engineering Department had made some changes to all the standard hours for each board type. This presented no problem; the model had been built with a front end that allowed new data to be entered interactively. It did not have to be reprogrammed for a rerun on the new standards. In this application it was important to input real historical data on the flow of materials. This was done by entering data of actual production schedules from an external file and loading the model with the correct board population mix. The NCR team found it very useful to be able to stop the simulation at any time during a run, input a new board population mix, and restart the simulation without destroying the previously collected simulation data. The model could thus be continually updated according to the current conditions at the work center.

See Why animated graphics allowed viewing of input and output queues, move-

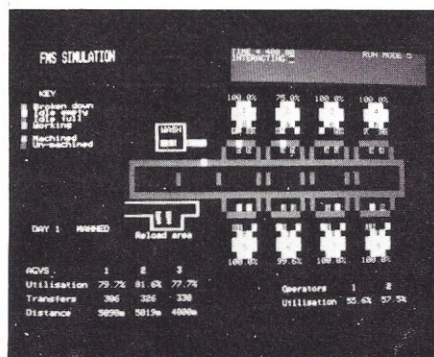


Photo 1. The operator calls up a diagrammatic image on the color display terminal of the See Why system to study the effects of alternative procedures and designs in a manufacturing plant.

ment of tote boxes, and statistical information—data that indicated where the process bottlenecks were to be found. According to Deaver, the most important result was showing that a \$200,000 investment for a conveyor system was unjustified.

NCR engineers are currently developing a number of other See Why models. In process are a proposed Automatic Guided Vehicle system and a model of the conveyor system for the Automatic Visual Tester for inspecting circuit boards prior to wave solder.

In this case history, an automobile plant in Detroit avoided a potential production loss of about \$120,000 per week and a slowdown in producing new vehicles. The See Why system identified and corrected the logic in a computerized network. Simulation of a computerized conveyor network designed to carry, via a buffer, car bodies from two robotic lines to four manual finish lines was carried out to determine the logic applied to programmable controllers controlling the network. The technique was devised to determine how many motorized slings the network

required, as well as to validate the computer control system.

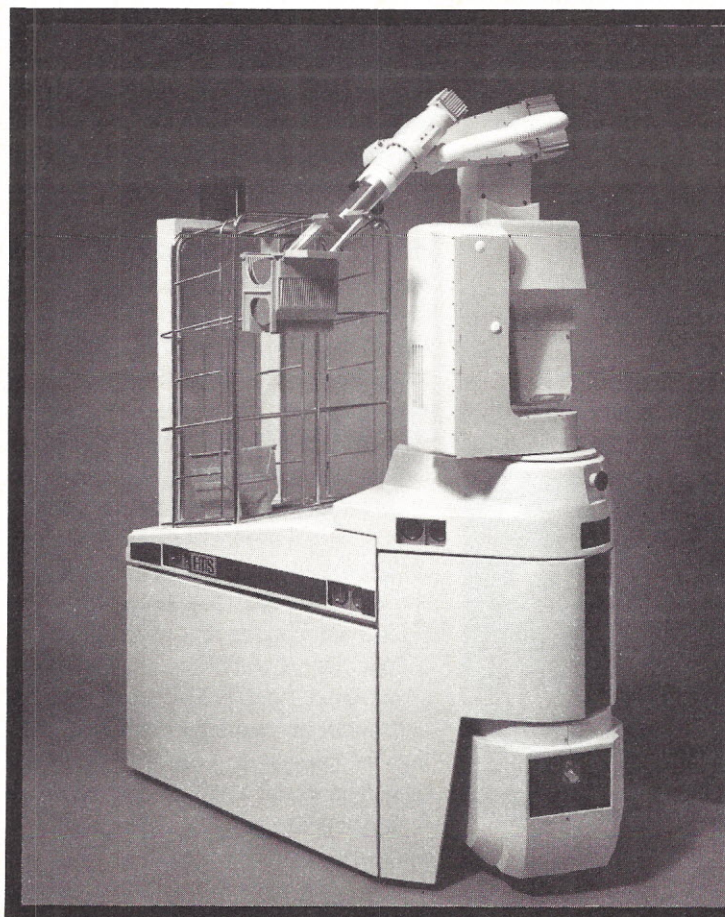
Several constraints in the system merited investigation: whether the input rate of the buffer inventory equaled at all times its output, whether the autobodies left the buffer in exactly the same sequence as that in which they entered, and whether the control rules could operate with any combination of failures at the load and unload stations. All 72 conveyor stops and the length of time it took for a motorized sling to travel between two adjacent stops, a value of within one hundredth of a minute, were included in a detailed model of the conveyor system. The logic, as designed by the network's suppliers, was then imposed on the model. Once set in motion, the model enabled the suppliers to validate it by checking the logic and the timing of the slings between different conveyor stops. Then, using See Why's interactive capability they imposed various breakdowns of load and unload stations. As a result of the breakdowns, the logic of the conveyor network failed and caused a loss of sequence through the buffer. In other conditions, simulation revealed that

the conveyor network would jam when the system's logic could not resolve competing demands for specific routes through the network.

Animated graphics revealed the source of the discrepancies and logic errors. A number of management personnel took part in the tests and were able to solve the problems so their system met its design objectives. The complete study involved one analyst and two man-weeks. It was estimated that the production loss that would have resulted had the logic not been corrected would have been about \$120,000 per week. More important, production buildup of the new vehicle and its subsequent launch would also have been delayed several weeks.

These two case histories illustrate some of the ways state-of-the-art simulation technology can be put to good use in designing manufacturing systems. It is certainly less risky and less costly to simulate before you automate.

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A THREE-AXIS JOYSTICK WITH NO MOVING PARTS

Rugged three-axis joysticks for industrial applications tend to be expensive because of their complex mechanical linkages. The joystick described here offers both mechanical simplicity and low cost. Since there are no moving parts to wear out, the device has a long life. It is also resistant to dust.

The joystick's sensor is a disk with four strain gauges (SG) attached at points equidistant around the disk's surface (Figure 1). A handle is attached to the center. The strain gauge outputs are not orthogonal, so a decoding circuit is needed to separate the signals (Figure 2). A force in the Y axis produces equal outputs from all four gauges. A force in the X axis produces equal and opposite outputs from SG2 and SG4. A force in the Z axis produces equal and opposite outputs from SG1 and SG3.

A fifth strain gauge is needed to provide a temperature-compensated reference. SG5 is mounted close to the disk on a small, unstressed piece of disk material. This method is appropriate for most industrial applications. For military applications with wide temperature ranges, bridge strain gauges should be used so that each gauge provides its own precision reference.

In Figure 2, instrumentation amplifiers Z1 through Z4 amplify the strain gauge outputs using SG5 as a reference. Operational amplifier Z7 separates the Y axis by

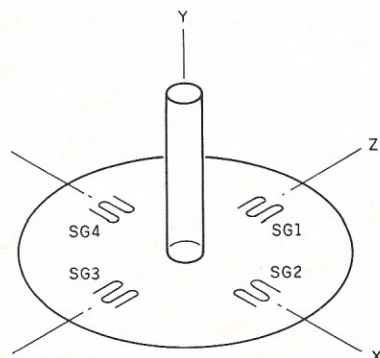


Figure 1. Four strain gauges are attached at points equidistant around the disk's surface and a handle is attached to the center.

William S. Tighe
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Carson City, NV 89702

summing the amplified outputs of the four strain gauges:

$$Y = A7 \times 60 \times (SG1 + SG2 + SG3 + SG4).$$

The instrumentation amplifiers Z5 and Z6 separate the Z and X axes by taking the differences $Z = A5 \times 60 \times (SG1 - SG3)$ and $X = A6 \times 60 \times (SG2 - SG4)$.

Adjustment of the circuit shown requires that SG3 and SG4 be closely matched. This should not be a problem since strain

gauges are sold in matched pairs. If they cannot be matched, a balance pot can be added in series with R5 and R6. The first step is to adjust R7 so the outputs of Z3 and Z4 bracket zero. Next, R1 and R3 are adjusted for zero at the Z and X outputs. R7 can now be adjusted for zero at the Y output. R17, R19, and R20 are now adjusted to obtain the desired force-to-voltage gain for each axis.

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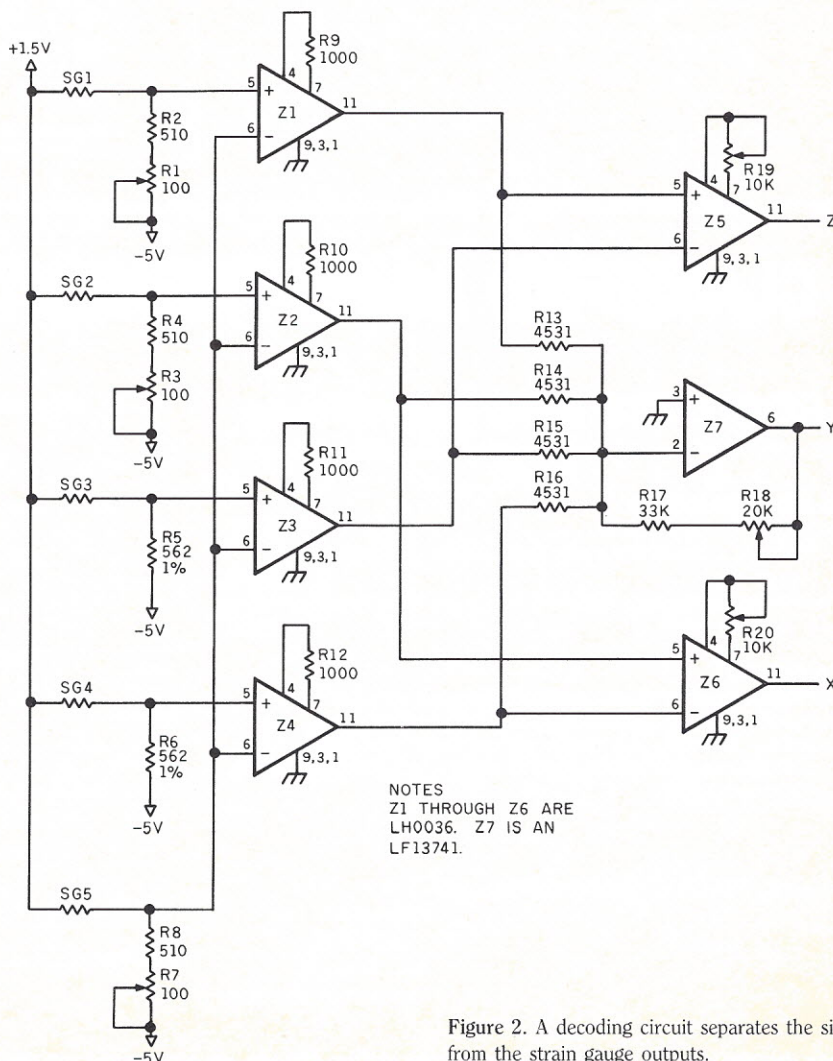


Figure 2. A decoding circuit separates the signals from the strain gauge outputs.

MAINTENANCE ROBOT CONTROL SYSTEMS

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Source ID: BCE252

Selecting a control system is one of the major problems in the design process of any robot. Many things must be considered: precision, accuracy, ease of use by the end user, implementation, and, of course, cost. Perhaps the most overlooked step is defining the environment in which the machine will operate and its function in that environment.

In deciding upon a control system for a maintenance robot, such as an autonomous vacuum floor sweeper, floor washer, or floor waxer, we considered four basic types:

- 1) tape or track following
- 2) bump and turn
- 3) sonar ranging system feedback, and
- 4) teach and playback.

The first method is based on a combination of a sensing system and a track. The track may be black tape on a white floor, a stripe painted on the floor in a contrasting color or a UV fluorescent material, an imbedded magnetic track under a floor, a slightly radioactive tape, or a buried cable with RF signals on it. The advantages of this method are good accuracy, low sensor cost, and ease of use. Disadvantages include the need of physical tracks, the possibility of floor modifications, and the length of time it takes to "program" a floor.

The bump and turn method consists of a robot with whisker or bump switches and a control algorithm that moves the robot

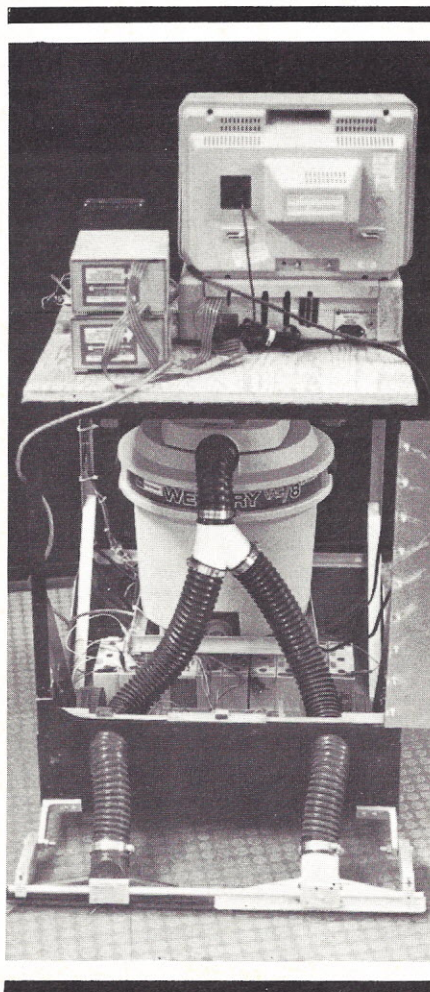


Photo 1. A prototype utility service robot. A simple interface and a BASIC program provide the starting point for developing floor coverage algorithms using open loop techniques.

in a direction other than its current one when a switch closure is sensed. This system is inexpensive and easy to implement. However, there is the possibility of damage to the robot's operating environment. In addition, it takes the robot a long time to complete its task, since complete coverage requires duplication by overlapping "random" paths.

Sonar ranging systems, while costly, are very precise. These systems operate on the same principle as a bat's ranging system. An electronic element emits a burst of high frequency sound while a counter times how long it takes for the burst of sound to be reflected off an object in its range. By using this time, the distance between the unit and the object in its path is computed. Sonar is complicated by spurious echoes and the time delays required for round-trip passage of sound.

In the teach and playback system, one leads the robot through its path and then executes this taught routine at a later time. This method's advantages include no costly sensors or tracks, no damage to the environment (providing it is defined), and ease of programmability. Its disadvantages include a high possibility of error due to open loop navigation and the necessity of a defined environment.

We chose the last method after deciding it was possible to operate the robot in a defined environment. The requirements of this environment are that no obstacles may

appear after the robot is programmed, the surface may have to be prepared for the robot (large objects, for example, must be removed from the robot's path in the case of the vacuuming robot), and no humans or animals may cross the robot's path. This method also allows the robot to be used for many applications, and it is easily reprogrammable.

We used the Apple II+ as the control computer. An interface card is required to control the two drive motors. The robot is configured as a three-wheeled base: one wheel is a caster and the other two are independently driven. The Apple interface is shown in Figure 1. Three annunciator (TTL) outputs are used from the game port and then buffered by a 74LS241. The buffer outputs are then optically isolated from the motor drive circuit by using an IL1 or equivalent optoisolator. Inputs "LEFT" and

"RIGHT" drive the motors through transistors arranged in a Darlington pair for high current gain. The "DIR" input, the direction bit, thus selects the proper polarization of the motor leads.

Two 12 VDC pancake motors can be used as drive motors. Both are driven simultaneously in order to go straight in either forward or reverse direction. They are operated either differentially or independently when making left or right turns. The differential mode allows for sharper turns, while the independent mode generates a more gradual, less accurate turn.

The control program is written in Applesoft BASIC. First it sets the output bits to shut the motors off. Then it initializes the variables used and sets the direction relays to "forward." It then clears out two arrays, A\$(x) and B(x). The pro-

gram then prompts the user to input a command: (A)head, (B)ack, (L)eft, (R)ight, (S)traight, (G)o, or (Q)uit. If the command is either Ahead or Back, the program sets the duration variable equal to one. If a Quit is entered, the program goes through the reset procedure. An entry of Straight, Left, or Right causes the computer to ask for a duration in approximate seconds of motor travel. If the command is Straight, the duration is adjusted to be half that of the Left or Right command because both motors must be activated, and the procedure takes twice as long as activating one motor. The motors are then activated for as long as variable "D" is set for. The motors are then shut off and the next command is input. If the Go command is entered, the program will execute a routine that will read through the A\$(x) and the B(x) arrays for the proper commands and

Listing 1. A simple Apple BASIC program to control the open loop playback of a trajectory.

```

10 REM *****
20 REM * DUAL DC MOTOR CONTROLLER *
25 REM * MITCHELL S. ALEXANDER *
30 REM * N.Y. INSTITUTE OF TECHNOLOGY*
35 REM *
40 REM * POKE ASSIGNMENTS: *
42 REM * -16296,0 =AN(0)=L MTR ON *
44 REM * -16295,1 =AN(0)=L MTR OFF *
46 REM * -16294,0 =AN(1)=R MTR ON *
48 REM * -16293,1 =AN(1)=R MTR OFF *
50 REM * -16292,0 =AN(2)=MTRS FWD *
52 REM * -16291,1 =AN(2)=MTRS REV *
60 REM *
62 REM * VARIABLE ASSIGNMENTS: *
64 REM * CMD$= COMMAND *
66 REM * B= INPUT DURATION *
68 REM * D= CALCULATED DURATION *
70 REM * A$(X)= COMMAND LIST *
72 REM * B(X)= DURATION LIST *
74 REM * X= INIT ARRAY COUNTER *
76 REM * T= DURATION TIME COUNTER *
78 REM * PNTR= COUNTER INDEX *
90 REM *****
100 REM INITIALIZE ARRAYS
110 DIM A$(2000)
120 DIM B(2000)
130 HOME
140 PRINT "MOTOR MOVER V1.1"
150 PRINT "COPYRIGHT N.Y.I.T. 1985"
160 REM SHUT MOTORS OFF
170 REM DIRECTION = FWD
180 POKE - 16295,1
190 POKE - 16293,1
200 POKE - 16292,0
210 REM INITIALIZE COUNTERS
220 Z = 0:PNTR = - 1
230 PRINT "RESET"
240 FOR X = 0 TO 2000
250 A$(X) = "0"
260 B(X) = 0
270 NEXT
280 PRINT "INIT PROCEDURE DONE"
290 HOME
300 REM INPUT COMMAND
310 VTAB 20
320 PRINT "CMD=<A>HEAD <B>ACK <L>EFT <R>IGHT"
330 PRINT "<S>TRAIGHT <G>O <Q>UIT <ANY>=PAUSE"
340 VTAB 1
350 INPUT "CMD> ";CMD$
360 IF CMD$ = "A" THEN B = 1: GOTO 460
370 IF CMD$ = "B" THEN B = 1: GOTO 460
380 IF CMD$ = "Q" THEN 130
390 IF CMD$ = "G" THEN 700
430 REM INPUT DURATION
440 INPUT " DUR>";B
450 REM STORE CMD,DUR IN ARRAYS
460 PNTR = PNTR + 2
470 A$(PNTR) = CMD$
480 IF CMD$ = "S" THEN D = INT (B * 250): GOTO 500
490 D = INT (B * 500)
500 B(PNTR + 1) = D
510 REM ECHO COMMANDS BACK
520 PRINT : PRINT CMD$;"FOR ";B
530 REM MOVE ROBOT!
540 FOR T = 1 TO D
550 IF CMD$ = "A" THEN POKE - 16292,0
560 IF CMD$ = "B" THEN POKE - 16291,1
570 IF CMD$ = "L" THEN POKE - 16294,0
580 IF CMD$ = "R" THEN POKE - 16296,0
590 IF CMD$ = "S" THEN 610
600 GOTO 640
610 REM STRAIGHT
620 POKE - 16294,0
630 POKE - 16296,0
640 NEXT T
650 REM SHUT MOTORS OFF
660 POKE - 16295,1
670 POKE - 16293,1
680 REM GET NEXT CMD
690 GOTO 290
700 REM PLAYBACK ROUTINE
710 IF A$(1) = "0" THEN PRINT "NO ROUTINE IN MEMORY"
720 GOTO 290
730 REM SHUT MOTORS OFF
740 REM DIRECTION = FWD
750 POKE - 16295,1
760 POKE - 16293,1
770 POKE - 16292,0
780 PNTR = - 1
790 PNTR = PNTR + 2
800 CMD$ = A$(PNTR)
810 IF CMD$ = "0" THEN POKE - 16295,1: POKE - 16293,1: POKE - 16292,0: GOTO 290
820 DUR = B(PNTR + 1)
830 FOR T = 1 TO DUR
840 IF CMD$ = "A" THEN POKE - 16292,0
850 IF CMD$ = "B" THEN POKE - 16291,1
860 IF CMD$ = "L" THEN POKE - 16294,0
870 IF CMD$ = "R" THEN POKE - 16296,0
880 IF CMD$ = "S" THEN POKE - 16294,0: POKE - 16296,0
890 NEXT T
900 REM SHUT MOTORS OFF-FETCH NEXT CMD
910 POKE - 16295,1
920 POKE - 16293,1
930 GOTO 790
940 END

```

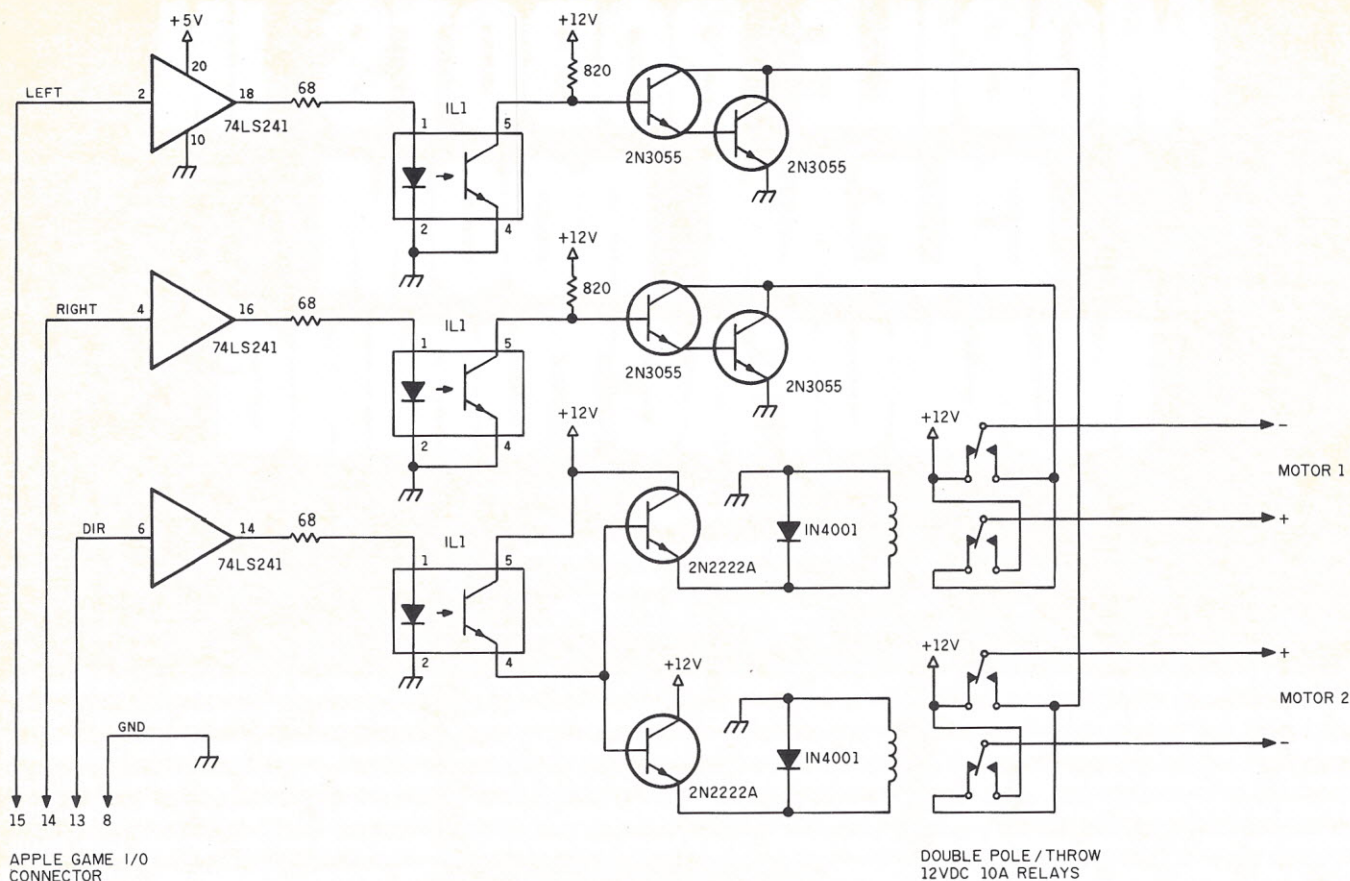



Figure 1. An interface between LS-TTL outputs of the Apple II+ game I/O connector and two reversible DC motors. DPDT relays control direction from pin 13 (DIR) of the game connector. Power is applied via optically isolated 2N3055 Darlington transistors controlled by the signals on pins 14 (RIGHT) and 15 (LEFT) of the connector.

durations as they were taught in the "teach" routine and then activate the proper motors and/or relays accordingly. The next command and duration are fetched and output until the routine is completed.

In order for this routine to operate correctly, the robot must be aligned to an easily found starting point so that the routine can be repeated with reference to the same initial point.

This control system could be improved in several ways. Three switches could be used to input the commands in the form of a teachbox—two for the motor direction and movement and one for stop, wired into the PB inputs of the Apple. A different computer with parallel input ports could be used in conjunction with optical encoders on each wheel. Finally, emergency bump switches could be placed on the front of the robot and wired into the PB inputs.

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MOBILE ROBOTS IN CLEAN ROOM MANUFACTURING

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The world in general seems at times to be getting more crowded, more disorganized, and dirtier. In sharp contrast is the progress in clean room technology, with its growing use of robots to decrease ambient particulate matter, reduce congestion in the work aisles, and bring about a smoother operational flow. An examination of some of the problems associated with today's human-operated clean rooms will illustrate the advantages of robotic transfer of materials.

Three sources of particulates that cause yield losses in clean rooms are process equipment, incoming materials, and people. Equipment contributes approximately 30 percent of particulate defects on in-process materials. Even clean material containers can add another 5 to 10 percent to the particulate count. Approximately 15 percent of the particulates comes from incoming materials such as chemicals, gases, or, in certain manufacturing processes, disposable utensils or accessories. People, in spite of being encased in various types of "bunny suits," contribute up to 40 percent of the particulate matter in a clean room.

Air conditioning is the major operating cost for a clean room facility. Class 10 environments can be achieved by continuous filtering of the clean room air, but even with the particulate count down to 10 particles per cubic foot of air there still remains a high probability that particulates will come to rest on material surfaces. The increased size of wafers in the semiconductor industry has brought with it a greater surface capture area. Air tur-

bulence created by people in motion dislodges particles clinging to walls and other surfaces. The human side of clean room operation is perforce a day of confinement to specific work areas, isolated from coworkers by a bunny suit and a face bubble.

Many solutions to these problems have been put forth. Incoming materials are passed through cleaning stations prior to entering the clean room. Chemicals and gases are filtered down to 1/10 micron. Personnel are wearing suits made of new high-density fabrics, with face masks and portable breathing apparatus. Considerable effort is being expended in cleaning up the equipment. Putting all working or moving parts below the surface so they have less chance of contaminating the in-process material is another approach. Attention has also been focused on the methods used in cooling electronics and mechanical parts. Expensive laminar flow hoods are placed over equipment, only to find out in some cases that internal cooling fans stir up generated particles. Also, laminar flow is interrupted because of boxlike equipment design. (We should take a lesson from European car manufacturers in minimizing air turbulence.) New concepts in lubricated mechanisms such as ferrofluidics also help. Equipment servicing is provided from the service aisles, sealed away from the manufacturing aisles.

Particulate matter from equipment and incoming materials can be controlled; it is the particles generated and disturbed by *people* that present the most difficult challenge. Perhaps the best way to meet

this challenge is to remove people from the clean room environment. Since personnel are used primarily for material transfer and checking on the operational status of equipment, computer technology—integrated with robots—can take over, ensuring process repeatability and product quality. Furthermore, the gentleness of robotic handling is especially desirable for brittle materials like silicon wafers.

Why, then, have robots not as yet been widely introduced into clean room technology? For one thing, overhead gantry robots, with their heavy arms moving along a metal track, generate particulates that could be swept onto the work surface. Also, their arms cannot reach down from 8- to 10-foot ceilings and into work areas in the back of the workstations. A wall-mounted robot, while quite clean, nonetheless has to reach over material in process, sweeping ambient particulates onto the work surface and any exposed materials. Both these robotic systems have the drawback of limited flexibility—what happens when material must travel back and forth between workstations? Also, what would be the cost of having robotic arms on each workstation?

Another approach has been conveyor systems on tracks. These travel between islands of automation with people at both ends, providing material transport from point to point. They too are limited in flexibility, especially in environments with complex and sometimes unreliable process equipment. Extremely complicated schemes must be provided to accommodate frequent process flow changes or

to bypass malfunctioning equipment.

What is needed is a mobile, autonomous robot to load and unload workstation materials ports, communicate its actions to a central control system, and accept instructions from control to accommodate priority situations. (The robot must incorporate safety features as well, to protect the personnel who will from time to time be sharing its work area.)

The characteristics of such a robot include:

- Placement accuracy of better than 10/1000 in.
- Repeatability of 10 mils
- Batteries that can be recharged whenever the robot is stationary and performing some transfer operations
- Computer systems able to withstand

minor power failures, and that have redundant databases and the ability to transfer information rapidly

- Reduced generated or transmitted vibration

The introduction of such a robotic system would have several beneficial effects:

- Simplification of air filtration and conditioning systems, with a resultant lowering of construction and operating costs
- Reduction of the typical 6-foot aisle down to 30 to 35 in. (With laminar flow rooms costing \$600 per square foot, space reductions would significantly lower the costs of building and running a clean room.)
- Optimization of process flow sequence

for equipment use and rework

- Placing the entire operating mechanism outside the clean room area

Flexible Manufacturing Systems (FMS) has developed a clean room robotic vehicle (Photo 1) outfitted with an Intelledex Model 605 arm. The particulars of the FMS system are as follows:

The vehicle has sonar sensors to detect obstacles. Since the robot is bidirectional, the sensors are placed all around it. Detection distance can be set; whenever an obstacle is detected, a voice module tells it to move and eventually sends an alarm to the supervisor terminal. All panels on the vehicle are touch sensitive and stop the robot and arm upon contact with a person or object. Pinch points are enclosed, and the arm has encoder limiting that stops its operation when it encounters a small pressure. There is also a flashing light to indicate that the robot is in service.

It travels at 1.5 ft./sec. The arm moves at 3 in./sec. but could be programmed to operate faster when no personnel are present. Average time to load or unload a container is approximately 30 seconds, dependent to some extent upon the complexity of arm movement required to access the manufacturing equipment. Two parts can be changed to accommodate different containers—the robotic end effector and the cargo bay at the rear. The arm, including the end effector, has a payload of 10 lbs.

Three wheels evenly distribute the vehicle's 600 lb. weight. The front drive wheel is wider, allowing easy turning over perforated or grate floors while minimizing wear. A gyroscopic system provides directional guidance, with distance measured by an optical encoder. These two measurements—direction and position—are used to accurately calculate the vehicle's position within 5/1000 in. The aerodynamic design reduces air turbulence both when the vehicle is moving and when it is sitting by a workstation. External materials were selected for their low particulate generation and high conductivity to minimize clinging of particulates. An electrostatic ground strap keeps the vehicle electrically neutral.

A comprehensive software system provides control and monitoring of vehicles and material flow. The manufacturing area is displayed graphically, showing the vehicle's position, work, and work in process

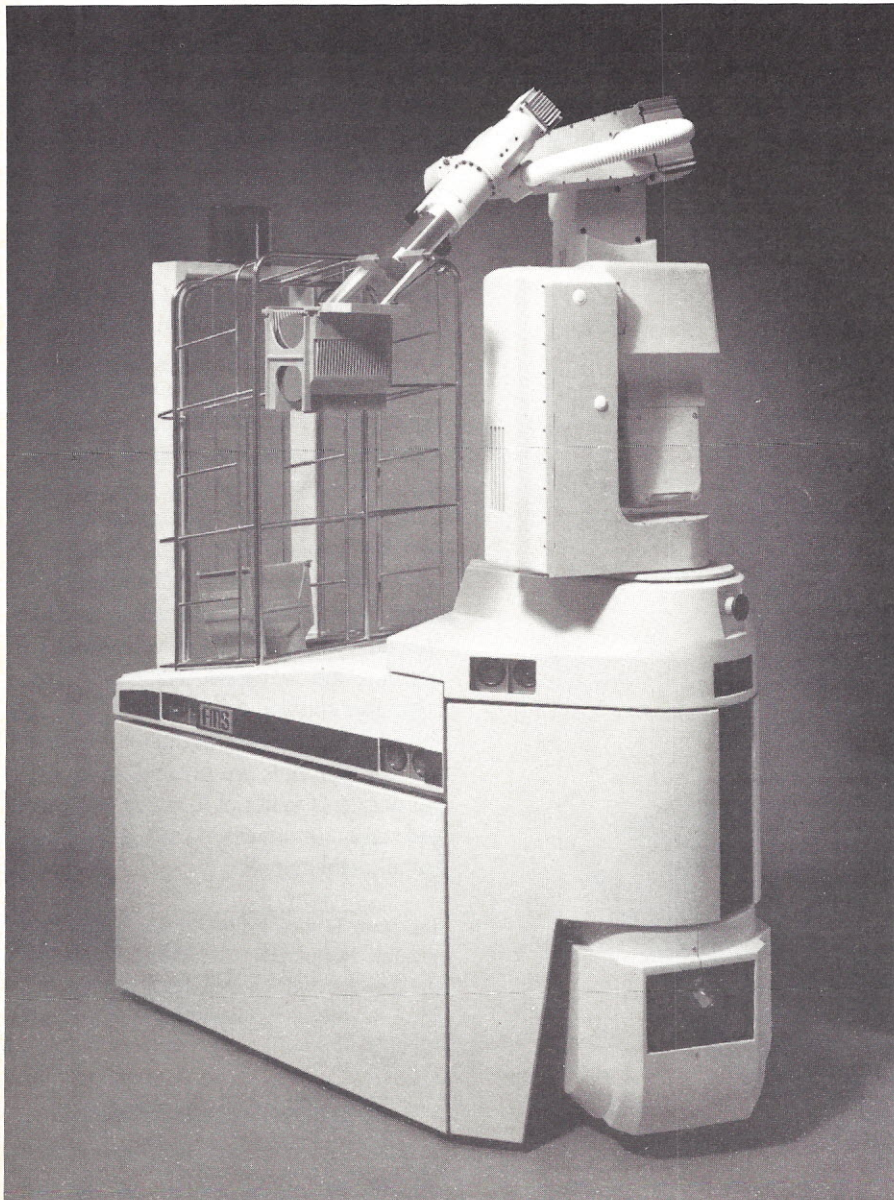


Photo 1. The clean room robotic vehicle consists of a six degree-of-freedom arm mounted on an automatic guided vehicle.

storage station placement, along with movement when it is occurring. Although it is oriented toward semiconductor wafer manufacturing, the menu tracks material lots, making available lot position, destination, and movement history. Production equipment status is monitored for availability to the material handling system. Operation and control from the supervisory terminal is also available as a database consisting of lots in process, physical data covering workstations, work in process stations, and obstacles to be avoided.

How is such a system to be installed in a manufacturing line? FMS has developed a software package that simulates material flow with vehicles and various work in process station locations. The input to this package consists of the features previously outlined. Simulated are such parameters as the number of containers accommodated by the work in process station, equipment availability, on-board average

storage capacity, and vehicle characteristics such as speed, transfer time, and docking period. Data output includes work in process queuing, vehicle use, manufacturing line throughput, and delays due to vehicle unavailability.

As installed, the system uses a wall-mounted infrared communication unit and a docking module consisting of a mirror placed on the workstation that lets the robot precisely determine its location. Operator terminals that allow communications to the computer system are connected at each work in process station and workstations as needed. A central computer, connected via RS232 and 422 lines, provides the communications network. The graphics terminal shows the manufacturing area and the robot vehicle's movement in real time. An uninterruptible power supply feeds the computer. The vehicle is simply brought into the work area and taught the movements for transferring and transporting material. The

path between stations is designated as well. Transfer at work in process stations follows pretaught instructions from the factory.

In addition to elimination of particulates from the clean room, several other areas of improvement serve to justify the cost of automating the manufacturing process. The gentleness of robotic handling leads to reductions in broken and chipped materials, and in-process lots are delivered to the right workstation in the proper sequence, eliminating the 3 to 5 percent mechanical yield loss due to misprocessing. The probe yield, or the number of good devices produced, rises as a result of heightened mechanical yield and also increases with fewer particulates. The productivity factor is very important as well. In a capital-intensive manufacturing line, all productivity increases translate to a better return-on-investment. With shortened production cycles, lower in-process inventory with faster product availability also serve to reduce product costs. Figures from Japan, where such systems are in use, indicate mechanical yield increases of 10 to 15 percent, moving from the present 80 percent up to the low 90s. Probe yields could rise from the current 40 to 50 percent up to the 80s or even 90 percent.

To summarize, FMS anticipates that mobile robots will be the next wave in automation. New technology in robotic arms suitable for mounting on vehicles, and enhancements in navigation technology with precise computer control, were the impetus behind the clean room system described herein. The ultimate in clean room manufacturing will be a lights-out area in which mobile robots will transfer and transport materials under computer control. No humans will be involved in equipment operations where in-process materials are present. With proper design of material handling hardware and station interfaces, particulates can be literally eliminated.

Joe Nava is Vice President for Marketing at Flexible Manufacturing Systems, Inc. He was the founder of Applied Materials Technology, Inc., a major semiconductor equipment supplier.

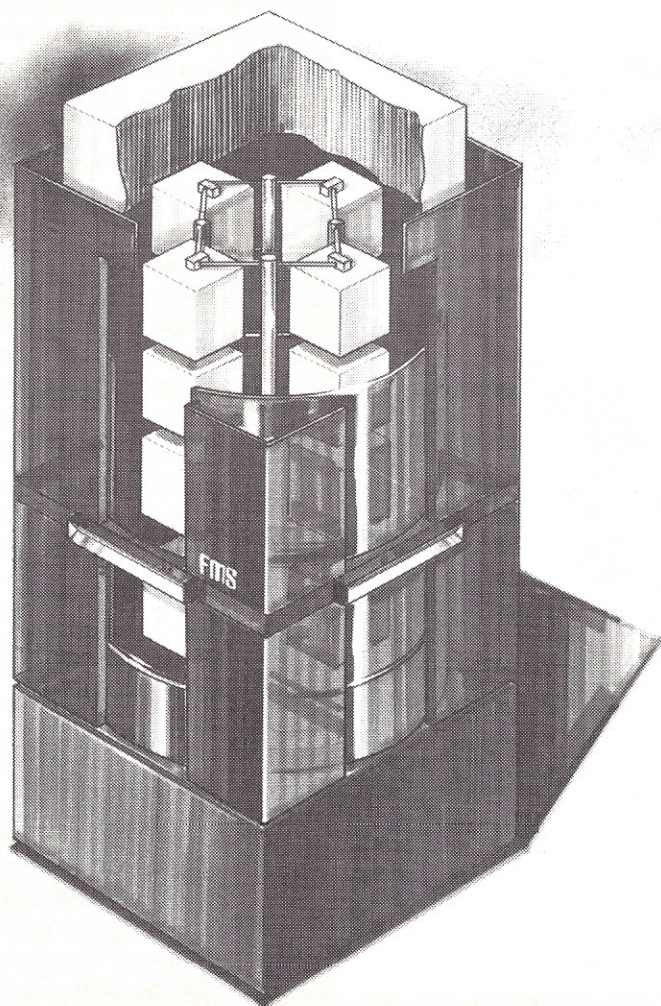


Photo 2. The work in process storage station features a rotating carousel that presents bins to the robot.

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Excellent	Good	Fair

In The Robotics Age

Edited by Stephanie vL Henkel

ROBOTICS IN JAPAN

The 1985 International Industrial Robot Exhibition was held September 11-13 in Tokyo, Japan. Robotics Age correspondent Harry H. Poole, president of Robotics of Rhode Island, Inc., was there and filed the following report.

Most of the 75 robotics exhibitors were Japanese, although their ranks included three American firms, one from Germany, and one from Sweden. Displays included both the latest working models and robots still in the R&D stage. The Born Robot (Photo 1), an industrial bipedal device, is the project of a group of universities and Motoda Electronics. The robot can walk; further developmental stages will be to give it the ability to know where it is, to interact with humans, and to avoid obstacles.

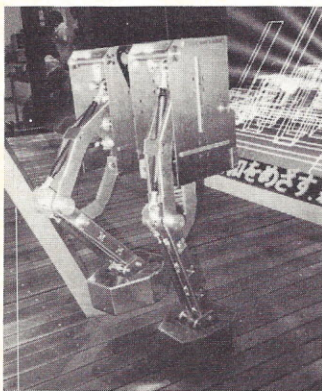


Photo 1.

Two other interesting mobile robots were a base built to carry a wheelchair (Photo 2) and Meldog, a guide vehicle for the blind (Photo 3). Meldog is approximately 18 in. high, 18 in. wide, and 36 in. long. It carries both sonar and a CCD-based vision system and can detect the edges of a road, its own geographic position (by means of



an internal database and artificial beacons set about the town in which it travels), and moving and stationary obstacles.

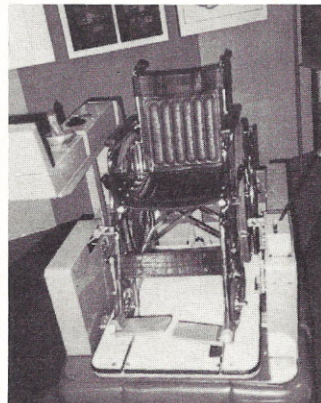


Photo 2.



Photo 3.

Fanuc displayed both a large arm robot (Photo 4) and an automatic guided vehicle (Photo 5) designed to transport a stationary robot around an industrial facility. Murata showed its "Robo-family" including the

Robo-trailer, which follows a painted line, and the Robo-train, which runs on rails and can carry loads of over 10,000 lbs.

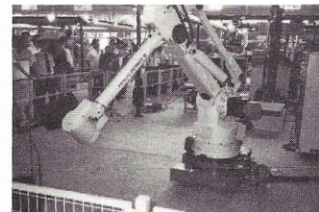


Photo 4.

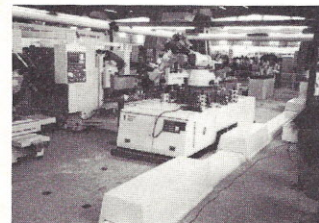


Photo 5.

Mitsubishi demonstrated a multiple arm control system consisting of four robots (Photo 6). The first arm picked up dice and passed them to the second, which passed them to the third and thence to the fourth, which threw the dice. The firm also presented information about its completely automated plants in which Mitsubishi robots, according to the speaker, produce computer chips at twice the rate of typical American

facilities and with a significantly lower defect rate. Pick and place assembly robots and optically guided overhead gantry robots are used in the operation. A recently completed plant makes 7 million 256 K DRAM chips per month.



Photo 6.

An exhibit by Suwa Seikosha illustrated assembly robot speed and accuracy, with relative arm movement (between two arms) of 154 in./sec. and 101 in./sec. in a single arm. Positional accuracies of 0.0008 in. have also been achieved.

Yaskawa's exhibit stressed sensor capability, with demonstrations of molten pool vision sensors, laser sensors, and one sensor that allows the viewer to look straight through a welding arc. The firm also displayed intelligent deburring (contour following), intelligent welding (seam tracking), intelligent assembling (different part sizes on a moving conveyor), and a single vision system controlling two robots simultaneously.

Many exhibitors were stressing vision. Sony demonstrated a robot equipped with a system that tracked a ball as it moved around a maze (Photo 7). On command, the robot's arm reached down to pick the ball up. Nippon Avionics, a joint venture of NEC and Hughes Aircraft, offered a vision system that recognizes objects by shape. One of the more advanced vision systems available

In The Robotics Age

in Japan is that of the Ekagame Fushinke Company, which provided the PIC 2300 CCD camera used by Wabot (the organ playing robot) to read sheet music. The company has now developed a more advanced model, the PIC-2500.

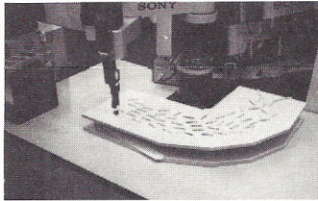


Photo 7.

The Swedish firm ASEA has established a subsidiary in Japan (Gadeluis K.K.) to sell its standard robots. ASEA has also obtained rights to sell outside of Japan SCARA robots made by the Japanese firm Nitto. Ac-

cording to one estimate, ASEA currently sells 15 percent of the world's industrial robots.

In addition to manufacturing operations, robots were performing test functions. Toshiba's device (Photo 8) tested an automated teller machine by inserting a bank card, typing in the proper password and transaction instructions, and withdrawing (simulated) money.

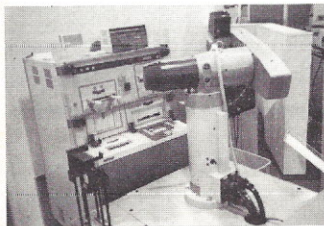


Photo 8.

The Japanese have established an International Robo-

tics and Factory Automation Center in Tokyo to carry out research and development in basic robotics technology. Among the 12 areas of research being pursued are work in sensor technology and artificial intelligence, in developing robots designed to assist the elderly and the handicapped, and investigating new materials for use in robot construction. The

center has an existing equipment and capital property base of \$1.2 million, and a budget over the next year of \$830,000.

All in all, it is obvious that the Japanese are striving to remain the leaders in industrial robotics and have, in fact, proclaimed as a goal the production of a machine endowed with artificial intelligence by the year 1992.

THE FIRST ROBOTS EAST

Robots East, the first major East Coast robotics convention, was held in Boston October 9-11 and drew an attendance of 4733. Sponsored by the Robotic Industries Association, the exposition included 75 exhibits and 175 exhibitors. The disparity between those two numbers was due to considerable doubling up in booth space (in some cases, as many as six firms shared display quarters). Exhibitors were mostly from the Northeast, and we received the impression that the robot manufacturers and systems integrators from the rest of the country were taking a wait-and-see approach to the new event. Many of the largest firms were there (GMF, Adept Technology, DeVilbiss, Polaroid), and several were conspicuous by their absence (ASEA, Cincinnati Milacron, Prab). The convention will alternate with Robots West on a yearly basis, and we will be interested to see who shows up for the 1987 Robots East.

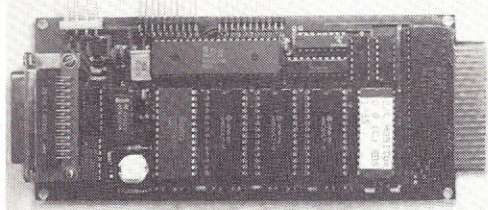
As was to be expected, most of the displays featured the smaller electric and pneumatic robots, parts inspection

systems, and lightweight end-effectors. East Coast industry is, for the most part, light industry, so there would have been little point in showing off automotive arc welders except to impress the hordes of students thronging the hall.

Every booth warranted a visit, but we found a few particularly memorable: Adept's advanced printed circuit board assembly cell that used the firm's manipulator, visual inspection, and sensory products; an adaptive automation system by Automatix using vision-guided robotics for PCB assembly and inspection; an X-Y positioning table from aXYZact, Inc. that solves problems such as deformation of the material being cut and reduces material waste; GMF's clean room robotic operation; IFT Engineering's universal end-of-arm tooling arrangement; and, finally, an extremely long, modular leadscrew made by LSI.

Four seminars were offered, each consisting of six or more presentations: robot safety, machine vision, justifying and financing high-tech equipment

TWO Z8 BASED CONTROLLERS



SLIM Z8 Controller

Packed on a 3" x 6.75" PC board the SLIM Z8 Controller offers 40K jumper-selectable memories of any combination of CMOS RAMs, EPROMs, or EEPROMs. With Zilog Z8671 CPU on board and one 8255 chip the controller has 38 I/O programmable lines to interface with the outside world. The EEPROM can be easily programmed at 5V with TINY BASIC command. The RS232 port and on-board simple monitor make SZC an ideal development tool and a dedicated controller. \$175

TINY Z8 Controller with 8 Channel A/D Converter

Tightly packed on a 1.7" x 6" PC board the Z8671 based controller offers a jumper-selectable 4K to 32K RAM, EPROM, and EEPROM combination of memories. In addition to 8 programmable I/O lines and a RS232 serial port the controller has 8 channel A/D converter with a choice of 8 or 10 bit resolutions. Along with on-chip BASIC the product is ideal for dedicated control and data acquisition. Power requirement is 5 Volts only.

Other common features for the two products include two counter/timer, 7 baud rates, and 6 interrupts.

Kustem Data Services, Inc.

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In The Robotics Age

purchases, and motion control.

RIA President Walter K. Weisel, who is also president of Prab Robots, Inc., chaired the opening press conference and released robot sales figures for the second quarter of 1985. "The financial analysts," Weisel said, "are beginning to pick up on the RIA's reports and view them as the true gospel." For the period ending June 30, unfilled orders stood at 2744 (\$413.9 million); new orders at 1350 (\$65.7 million); and shipments at 1524 (\$79.1 million). For the first two quarters combined, new orders were 3184 (\$251.4 million) and shipments were 2764 (\$142.9 million).

No breakdown has been undertaken to determine where the robots sold in this country are being made, Weisel said, nor do the dollar figures reflect import duties. The majority of robots being marketed in the U.S. are of foreign manufacture, but, Weisel concluded, "I

think we're looking at a very healthy industry with a lot of room to grow."

The RIA's attention has been focused also on some of the problems affecting the robotics industry. Among those mentioned at the meeting was that of mismanagement. Some of the major robot users have become their own suppliers, according to one speaker, with the result that those firms have become for all practical purposes closed shops. Another comment was that the robotics industry is still marketing-driven and that some companies would do anything to sell, including putting themselves out of business. The statement was made that more obstacles to robot installation come from management than from the shop floor, but that management has begun to feel sufficiently threatened by imported goods to warm up to robots as a means of increasing output and efficiency.

Robotec through its acquisition of a majority interest in **Automated Control Technologies** last July. Robotec is a development stage company formed to design, manufacture, and market advanced robotic equipment.

► **Robotics of Rhode Island and Independent Energy Inc.** have entered into an agreement to combine research and manufacturing resources in the development of intelligent mobile robots and related products. RORI was formed in May 1984 to produce and market low-cost mobile robots for homes and businesses. Independent Energy was founded in 1975 to develop and sell electronic temperature controls

for solar energy hot water systems.

► **Chesapeake Laser Systems, Inc. and Medar, Inc.** have entered into an agreement whereby CLS will manufacture laser-based machine vision systems for Medar. Medar will market the new gauge for CLS, as well as use it in the automotive automation systems the firm currently manufactures.

► **Robotics Research Corporation and Brown & Sharpe Manufacturing Company** have jointly announced that Brown & Sharpe has purchased a minority equity interest in Robotics Research and has acquired exclusive, worldwide

CORPORATE NEWS

► **Allen-Bradley** has acquired **Robotronics S.A.**, the leading European artificial vision company. Robotronics is a subsidiary of the French firm MATRA S.A., a diversified high-technology electronics company whose major activities are in the military and aerospace fields, urban transportation, robotics, telecommunications, and semiconductors. Its vision system has been marketed under the Visimat name.

► **Perceptron** has received an equity investment of \$1 million

from **General Electric Company** through GE's wholly owned subsidiary GEVENCO. According to a GE spokesman, the investment will permit the companies to work together on large automation projects.

► **Robotec Inc.** has announced delivery of the company's first programmable vision system to "a major Fortune 500 company," which will install the system in its advanced manufacturing laboratory for evaluation of applications in its manufacturing operations. The system was acquired by

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In The Robotics Age

rights to market Robotics Research K-Series robots and Type 1 control products for inspection and metrology applications.

► **Prab Robots Inc.** has announced its acquisition of the exclusive rights to manufacture all seven models of GdA robot products in this country. The agreement is between Prab and

EKE Robot Systems of Munich, Germany. Prab has been marketing the all-electric line of robots since April of last year. The company also announced the signing of a letter of intent to purchase from **Lamb Technicon Corporation** the FAB-TEC® and U-FAB product lines and all the company's assets, patents, and tooling.

SCIENCE & TECHNOLOGY

Researchers at **Carnegie-Mellon University** have created the Terregator, an autonomous robot with potential applications in transportation. The prototype is an untethered robot 64 in. long, 39

in. wide, and 37 in. high. It has six wheels, three on either side, powered by an on-board generator. The vehicle communicates with the host computer via a bidirectional radio link and has a microwave link

for television transmission. A remote host computer performs most of the computations required for path following. Navigation is carried out by locating the road edges in the television image, calculating deviation from center, and steering the robot back onto the path. The process is continuous.

Terregator's initial junkets have not been uniformly successful—vehicle failures have included driving off the road, into trees and walls, and around in circles. According to the robot's designers, the problems lay in program bugs, imprecise calibration procedures, and limitations of current hardware rather than in fundamental limitations of the techniques used. Terregator has, however, managed to navigate a 65-ft. outdoor path at a speed of

about 2 fpm. Work has begun on obstacle avoidance by means of sonar and stereo cameras, and future development might add a laser range-finder to the system.

In a project sponsored by the **Rehabilitation Services Administration**, researchers at **Tufts-New England Medical Center** are using the **Scorbot** teaching robot to investigate the use of commercial robot arms for vocational training of the handicapped. Handicapped persons are taught to use whatever motor skills they have to operate the robot. For the severely handicapped, the Scorbot can be controlled by voice command. Telephone switchboard operation is among the skills being taught, along with sorting tasks such as those taught in sheltered workshops.

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MEDIA INTELLIGENCE

A combined team of engineers from **General Electric's** Aircraft Engine Business Group and the **Massachusetts Institute of Technology** has been investigating potential uses of robotic systems for automating the deburring of various aircraft engine parts.

Since burrs come in unpredictable sizes and shapes, the team is facing the challenge of adapting existing technology to allow a robot to deburr precisely contoured engine edges without gouging them. The engineers have conducted experiments with optical, tac-



In The Robotics Age

tile, and acoustical edge sensing techniques; they have also tried to keep the deburring tools from bouncing and creating gouges by attaching them to the robot arm by means of variously configured spring mounts and a fluid mount containing an extremely viscous liquid. When the technology is ready for the factory it should be welcome—estimates based on a recent U.S. Department of Energy study indicate that nationwide, industry spends about \$3.9 billion per year on deburring operations.

Robo-Tech Systems of Dayton, Ohio, has received a \$50,000 contract from **NASA** to begin work on "Control Theory and End Effector Laws Using an Advanced Multiple Prehension Manipulator." The program will link an improved

Versagrip III Multiple Prehension Mechanical Hand to an advanced computer control system by adding complete force sensing to each of the three fingers. The finger sensor outputs will be used to position the fingers, thus determining the hand's gripping pattern. The mechanical hand will be able to contact an object while adjusting its gripping pattern, grasp the object, and maintain a controlled prehensile force.

Initially, the gripper could be used on the space shuttle arm to retrieve and replace objects in space. Other potential space applications include the assembly of space station components, satellite servicing and maintenance, space rescue, materials processing, and materials handling. Robotics and prosthetics will also benefit from the technological advances of the program.

MARKET RESEARCH

Robotics will, over the next 10 years, displace some 4 percent of the workforce throughout industry while creating nearly 50,000 robotics-related jobs. A report, "U.S. Industrial Robot Forecast and Trends: A Second Edition Delphi Study," recently issued by the Society of Manufacturing Engineers, goes on to predict that:

- Of the workers displaced by robots, 90 percent will remain with their companies. Most will receive lateral transfers to new jobs.
- The automotive industry will experience the highest displacement level, increasing from 5 percent this year to 18 percent in 1995. Electronics will go from 3 percent displacement to 15 percent.
- The automotive share of the robot market will decline from 51 percent to 26 percent because of relatively faster growth of sales to other industries such as electronics, which will double from the present 8 percent to 16 percent by 1995.
- By 1995, 15 percent of industrial robots will have two or more arms, 11 percent will be mounted on ceilings or walls, 21 percent will move along a track, and 90 percent will be computer-controlled.
- Vision, tactile, and other sensory devices will be included on 60 percent of all industrial robots, especially those used for inspection, assembly, and welding.

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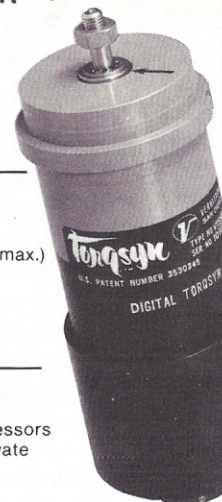
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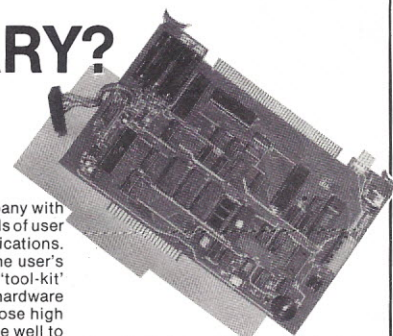


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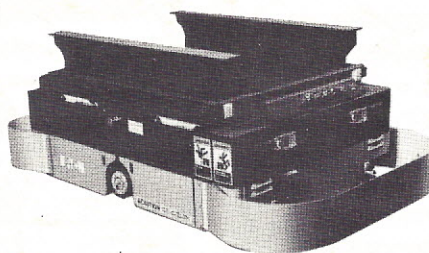
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Mobile Robot Product Guide

Eaton-Kenway

The Guide Wire Communications (GWC) series from Eaton-Kenway are micro-processor controlled, flexible path, unit load transporters that can operate as standalone systems or be integrated with other automated material movement and storage systems. An articulated frame and floating load deck permit the AGVs to keep loads stable over rough floors and negotiate grades. They can pivot up to 180 degrees on their own axes. The GWC transporters follow an electronic guideway in the floor, receiving directions from and reporting their status to a central control and communications computer. The vehicles do not require operator intervention to load, unload, and transport various material load sizes, weights, and configurations.

Transfer decks come in three models. The standard GL model has a lift top that accurately positions the vehicle against a pickup/deposit stand and raises or lowers its deck to pick up or deposit a load. The optional GC model



features a conveyor top that can interface with a variety of powered, static, or gravity conveyors for input or output of material for processing or storage operations. The optional GS model features a shuttle top that picks up and deposits a load alongside the vehicle without driving under the pickup and deposit stand. The shuttle automatically extends under the load, lifts, and transfers it onto the GS vehicle. Reversing the shuttle motion deposits the load.

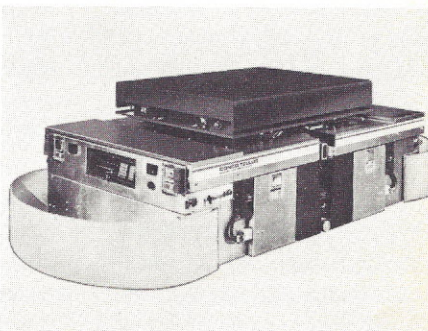
For more information, contact: Mark Houmard, Eaton-Kenway, 515 E. 100 South, Salt Lake City, UT 84102, telephone (801) 530-4301. Circle 60

Conco-Tellus, Inc.

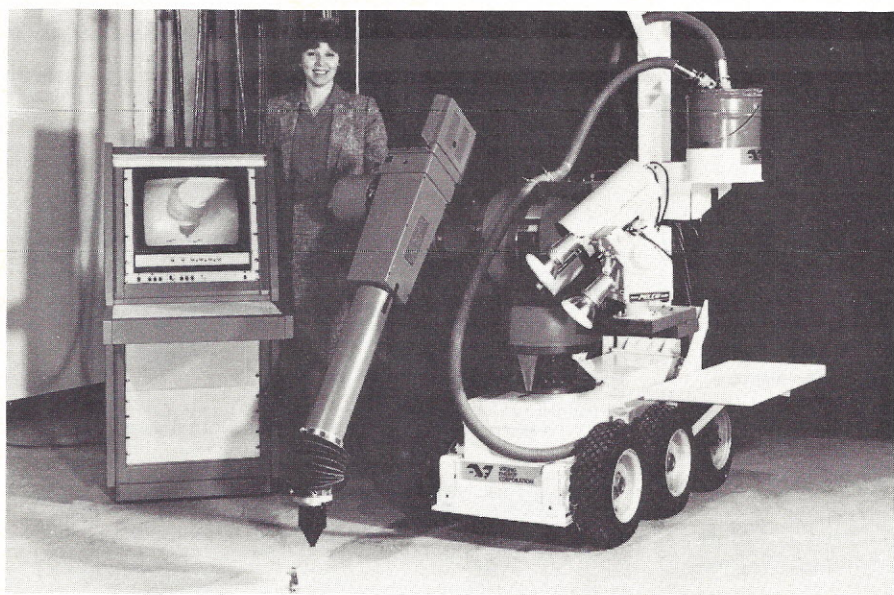
Conco-Tellus, Inc. is offering the UHPC automatic guided vehicle designed specifically as an 8-passenger standing conveyance. The AGV features a unique safety bar hand rail at each passenger station which lifts up and out of the way to facilitate entry to and exit from the conveyance. The UHPC also features a transparent, wrap-around bubble that permits unrestricted vision while providing protection from hazardous environments in manufacturing plants or similar facilities.



The firm also offers the UHE-4 and the UHE-8, standard AGV systems designed to provide efficient, horizontal transportation of loads and to match load sizes. The UHE-4 can carry 4000 lbs and load sizes of 48 by 50 in. The UHE-8 handles 8000 lbs and load sizes of 48 by 70 in. Each model comes with a standard fixed platform. Their repetitive stopping accuracy is ± 0.39 in. Their bidirectional capabilities permit interfacing with power roller stations and/or working in conjunction with non-powered stationary load stands.



For more information, contact: Conco-Tellus, Inc., AGV Division, PO Box 160, Mendota, IL 61342, telephone (815) 539-3450. Circle 62



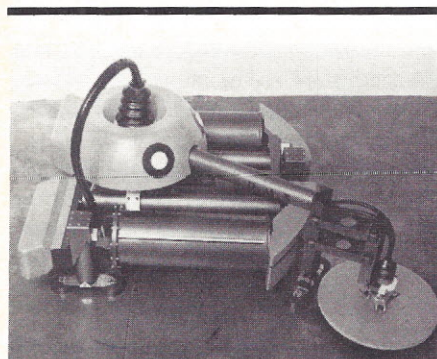
Viking Energy Corporation

The ROD Robot consists of a standard 6-axis American Robot Corporation robot mounted on a rough-terrain vehicle, and a tether management system that keeps the control cable off the floor. It was designed to work in hazardous, such as radioactive, environments. ROD can be remotely operated from up to 200 feet away, using a camera and monitor. The payload is 20 to 50 lbs and the

work envelope is 40 to 60 in., depending on the arm model. The robot has vacuuming capability and a gripper that allows it to pick up and use tools. Programming is carried out via a Motorola 68000-based UNIX system.

For more information, contact: Viking Energy Corporation, 121 N. Highland Ave., Suite 203, Pittsburgh, PA 15206, telephone (412) 363-7777. Circle 61

Mobile Robot Product Guide



Nu Engineering

The RM3 Robot was developed by Nordmed Shipyards of Dunkerque, France for marine applications such as high-pressure washing, deburring, painting, shot-blasting, and barnacle removal. The CR4, a modified RM3, can also be used to carry and handle objects in radioactive environments in nuclear power plants; to brush, paint or treat the surfaces of tanks; to apply ground coatings that give off toxic vapors; to perform industrial welding; to clean the sides of buildings; and to defrost aircraft wings and clean the outside of fuselages.

Using electromechanical adhesion pads, the RM3 can climb up and down, or back and forth on any metal surface. It can use suction pads to walk on flat or curved non-metal surfaces. The walking process consists of clutching the surface successively with the working base triangle and the transfer base triangle. The walking speed is 158 fph and the cleaning rate is 53,800 square feet per day. The CR4 is equipped with an ultrasonic obstacle detection system to ensure sure-footed movement across the surface. The electrical components of the robot are powered through a low-voltage cable tethered from the deck or ground power supply.

The robot can be operated by remote control or preprogrammed to perform its work automatically. Programming is carried out in Texas Instruments' Pascal MMP, a high-level language developed for real-time applications using systems designed around TMS 9900 family microprocessors.

For more information, contact: Nu Engineering, 12121 Bartlett St., Garden Grove, CA 92645, telephone (714) 894-1206. Circle 69

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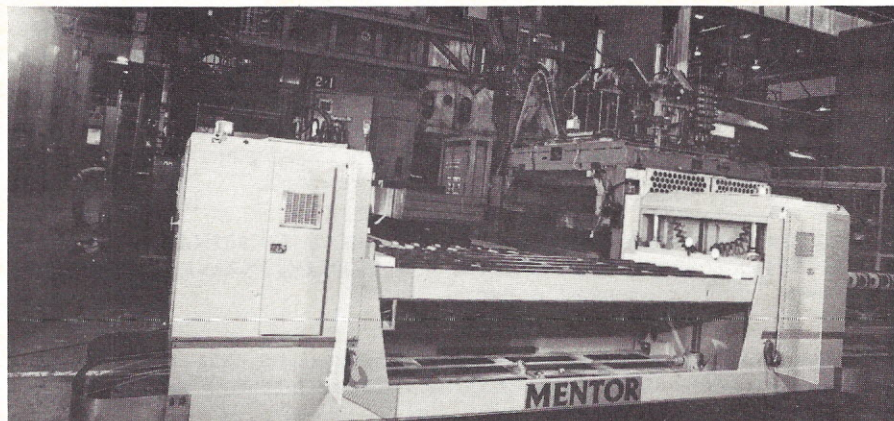
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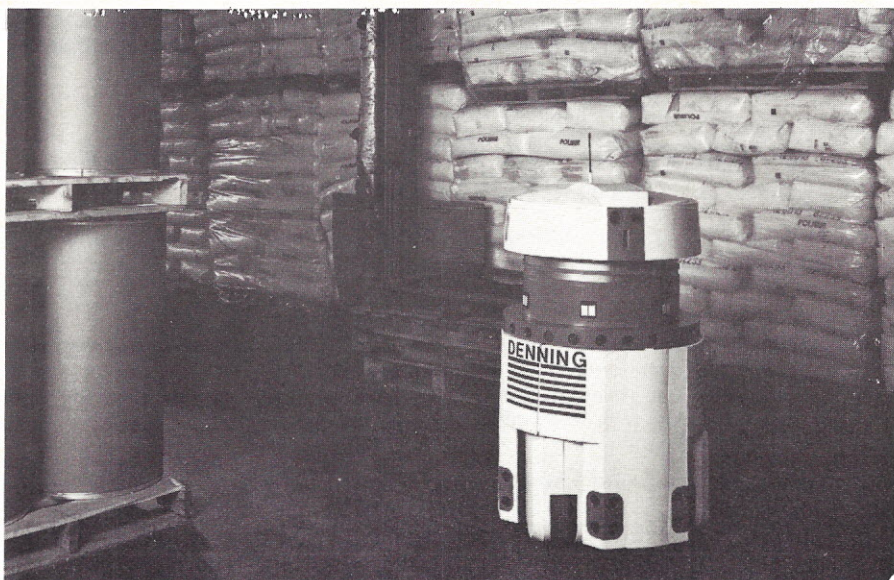
Mobile Robot Product Guide



Mentor Products, Inc.

Mentor Products, Inc. has introduced what the firm says is the country's first and only automatic guided vehicle system for moving sheet metal blanks. The AGV, with a 15,000 lb. payload, moves palletized blanks

from a blanking line to storage and from storage to a draw press. The system is totally automatic; the pallets are loaded onto the AGV, transported to a designated station, and unloaded by a command initiated by a photo eye.



Denning Mobile Robotics, Inc.

The Mobile Security Robot from Denning Mobile Robotics patrols warehouses and other large single-floor facilities in a random pattern by day or night. The Sentry is a 48 in., 400 lb., self-contained intrusion detection robot with ultrasonic and infrared sensors for both navigation and detection.

On-board multiple 68000 microprocessors enable the robot to construct and remember a map of a building, avoid objects, detect intruders up to a range of 150 ft., and silently

notify authorities, all without human intervention. Three on-board rechargeable 80 amp-hour 12 VDC batteries permit up to 11 hours of continuous duty. Additional options include on-board closed circuit TV and smoke detection.

For more information, contact: Denning Mobile Robotics, Inc., 21 Cummings Park, Woburn, MA 01801, telephone (617) 935-4840.

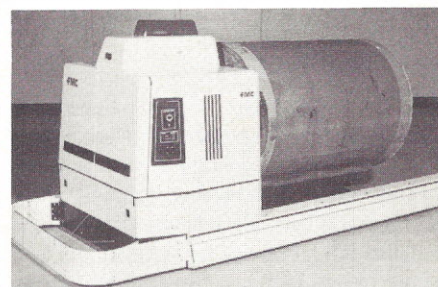
Circle 64

The vehicle is guided by signals received from a wire buried in the floor.

Dimensions are: 205 in. length, 60 in. width, 11 in. carrying surface height, and 48 in. maximum loading height. Speeds are 50-150 fpm. Safety features include ultrasonic object sensors, two safety bumpers (front and rear), four emergency stops, and two strobe lights. Off-wire operation is available under manual control. The accuracy registration is ± 0.125 in.

For more information, contact: Michael Urban, Director of Marketing, Mentor Products, Inc., 7785 Mentor Ave., PO Box 330, Mentor, OH 44061-0330, telephone (216) 942-8666.

Circle 63



FMC Corporation

FMC Corporation's Material Handling Systems Division's automatic guided vehicle carries paper rolls over predetermined paths. The self-propelled, battery-powered AGV follows a wire buried in the floor. The wire guide path emits a low-voltage electromagnetic field that is detected by sensors which report field strength to the vehicle's controller. Variance in the signal initiates steering corrections that keep the sensor centered over the wire guide path.

The AGV has capabilities for automatic loading and unloading, one- or two-directional travel at 185 fpm, and both computer and manual control. Payload is up to 3000 lbs. The vehicle can interface with storage racks, floor storage, and a variety of processing machines. In addition to rolls of newsprint, it can transport pallets, containers, and many other materials normally handled by forklifts. Safety features include emergency stop buttons, a 4-sided safety contact bumper system, warning lights, and fail-safe tracking.

For more information, contact: Larry Macko, Manager, Market Development, FMC Corporation, Material Handling Systems Division, 3400 Walnut St., Colmar, PA 18915, telephone (215) FMC-AGVS.

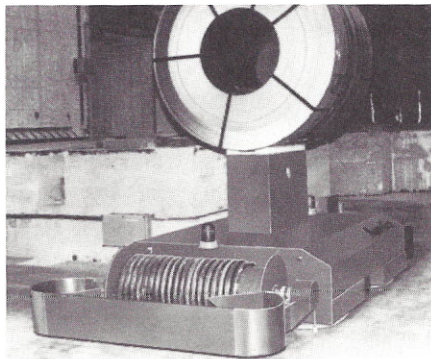
Circle 65

Mobile Robot Product Guide

Aero-Go, Inc.

Aero-Go's AGV system is designed to transport steel coils, dies, and heavy parts from storage to work stations and shipping areas at speeds of 45-90 fpm. The vehicle, described as having the highest payload capacity in the industry, can carry up to 100,000 lbs. It rides on a paper-thin film of air created by four slide-mounted air bearings which eliminate the possibility of floor damage. The air bearings are inflated with shop air via an umbilical hose on the vehicle's powered level wind/unwind reel. Two powered drive/brake system wheels are located under the vehicle; emergency stop actuator bumpers are at each end.

A guide wire in the floor directs the vehicle. Its location is determined by radio signal for information transfer at selected points. An on-board microprocessor interprets instructions,



monitors sensor inputs, and can pass information to a system computer. It also can issue functional commands to ensure operational and program compliance.

For maintenance and other purposes, the AGV can be operated manually and driven in

areas where there are no guide wires. Decks equipped with hydraulic rams or other systems for self-loading, unloading, and other automatic load-handling operations are optional. Safety features include constant monitoring of input information, hazard sensors, manual stop buttons, and interlocks for any mechanical, hydraulic, pneumatic, and electrical operations.

For more information, contact: Aero-Go, Inc., 1170 Andover Park West, Seattle, WA 98188, telephone (206) 575-3344 or (800) 426-4757. Circle 66



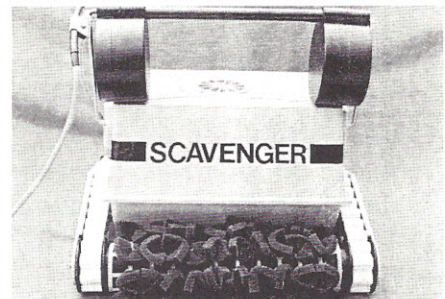
Robots Corporation

The TrakStar Series line of AGVs offered by Robots consists of eight models with payloads ranging from 1100 to 11,000 lbs. Model 4 is a forklift; the others are mobile platforms with a height of 16 in. Directions of travel range from unidirectional up to omnidirectional. Speeds are 200 fps. Model 1 is designed as an assembly AGV. Guided by a buried wire, the robot carries workpieces from station to station. It is unidirectional, weighs 550 lbs, and has a payload of 1100 lbs. An optional auto-

matic platform height adjustment is available.

The Robots Control Center (RCC) interfaces to distribution, manufacturing, or FMS host computers. It can also control the AGVs without a host computer. The RCC is MAP-compatible. Safety features include radar object detection, flashers, turn signals, and front safety bumpers.

For more information, contact: Robots Corporation, PO Box 13160, Lansing, MI 48901, telephone (517) 371-2460. Circle 67



Automation Technology Corporation

The Scavenger™ belongs to a family of microprocessor-based robots designed to scrub underwater surfaces and vacuum up contaminants in pools, cavities, sumps, tanks, and pits located in nuclear power plants and related facilities. It can clean both horizontal and vertical surfaces made of a number of materials including fiberglass, concrete, steel, and painted substances. A disposable filterbag collects debris and particulate matter. The device can also remove algae and other obstructions from the water inlet and discharge lines.

The robot is a 2-ft. cube, weighing 25 lbs. It is connected to its 60 Hz power supply via a 100-ft. floating cord. It carries two rollers, each equipped with a foam brush. The Scavenger can be teleoperated or maneuver autonomously for extended periods of time. Optional attachments allow the robot to function as an underwater transporter for radiation sensors and video viewing systems.

For more information, contact: Automation Technology Corporation, Overlook Center, 5457 Twin Knolls Rd., Suite 402, Columbia, MD 21045, telephone (301) 596-6665. Circle 68

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YSI SPRINGS INSTRUMENT CO.

YSI Division

YSI, Inc., P.O. Box 100, Springfield, OH 45387

767-7241

Telex: 205-437

Established: 1948

Employees: 400

Sales in 1983: N/A

Distributes products: Internationally

MANAGEMENT PERSONNEL

W. A. Schober, President/Chairman

W. J. Eggemann, Marketing/Sales Executive

W. J. Powers, Chief Financial Officer

W. J. Johnson/H. Trietley, Product Development

Inquiries should be directed to: R. Horn, Advertising Manager

PROPERTY/TYPE OF SENSOR

- chemical, dissolved oxygen
- conductivity
- humidity
- moisture
- pressure, barometric
- temperature sensors, platinum resistance detector
- temperature sensors, RTD
- thermistors, accessories
- thermistors, chip
- thermistors, glass bead
- thermistors, glass probe
- thermistors, wafer, NTC
- thermocouples
- thermometers, platinum resistance

COMPANY/PRODUCT NOTES

YSI manufactures sensors and associated instrumentation for measuring, monitoring and controlling temperature, dissolved oxygen, conductivity, pressure and humidity. Included are precision interchangeable thermistor sensors and temperature probes, platinum RTDs for process and standards applications, and thermocouple temperature probes, and transfer standards. Digital indicators, transmitters, and signal conditioners are also available for use with all YSI sensors.

W. A. Schober,

PRODUCT NOTES

YSI associates manufactures and distributes instruments for ion detection and health physics including survey meters, rate meters, scintillation probes, direct reading instruments and chargers, shields, and gas and liquid instruments.

SELECTION MENU

AUTOMATION CONTROL — INTERNATIONAL CYBERNETICS CORPORATION

Factory Automation Controls for

Flexible Automation Systems
Press Feeding Automation
Integrated Cell Controllers
Material Handling
MAP Compatible Systems
CIM Control Systems
Web Processing Systems

Advanced Technologies for

Fully Digital Brushless Servos
Distributed Servo Controllers
DNP™ Servo Technology
Coordinated Motion Control
Advanced CYBER-CIM Programming
Licensing Programs

Robot Controllers for

Vision Directed Systems
High-Speed Assembly
Arc Welding

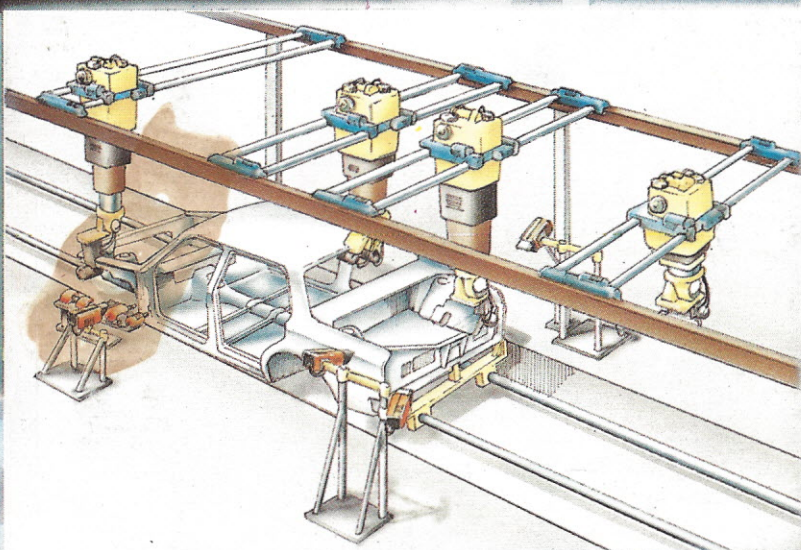
Overhead Gantry

Distributed Robotic Systems
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Intelligent Machine Controllers for

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*Patent Pending

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